Depositional controls on peat accumulation and coal characteristics, Dunollie and Brunner Coal Measures, Southern Rapahoe Sector, Greymouth.

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Abstract

This thesis reports an investigation of the stratigraphy and coal geology of upper Paparoa Coal Measures and Paleocene age Brunner Coal Measures in the Southern Rapahoe Sector of Greymouth Coalfield.

Lack of any clear lithostratigraphic or biostratigraphic definition for the upper contact of Dunollie Coal Measures with Brunner sediments has handicapped previous investigations. Stratigraphic criteria for the respective units are therefore revised. Brunner Coal Measures are divided into a "Brunner Formation" comprising Eocene coal measures and a "Paleocene Brunner Formation" comprising two members. The Brunner Conglomerate Member incorporates all conglomerates previously assigned to both the Dunollie and Brunner-P and the Brunner-P Member comprises Paleocene coal measures overlying the conglomerates. Dunollie Formation extends from the first carbonaceous horizon above transitional lithosomes to the last carbonaceous occurrence below Brunner Conglomerate Member. Revised boundary criteria are applied to new Dunollie Formation isopachs, cross-sections and paleogeographic models.

Over much of Greymouth Coalfield the Dunollie Formation and Brunner-P Member have only very minor coal occurrences, with organic matter more commonly occurring as leaf horizons or preserved rootlets. A key objective of this thesis is determination of reasons for relatively abundant coal occurrence in the Southern Rapahoe Sector, based on lithostratigraphic analysis of the coal measures and investigation of coal properties, including coal petrography, chemistry and palynology.

Both Brunner P and Dunollie coals are dominated by vitrinite. However, volatile matter, sulphur content and TPI are higher in Brunner P coals. Angiosperm abundance increases from Dunollie to Brunner P. This floral change affects volatile matter but not TPI, which was mainly controlled by a combination of water table and nutrient supply. Elevated sulphur content does not influence volatile matter, indicating that sulphur access was diagenetic and relatively late.

Unusually abundant coal occurrence in the Southern Rapahoe Sector is attributed to syndepositional faulting which constrained major fluvial activity to the north. Even so, overbank flooding and channel migration within anastomosing and meandering Dunollie fluvial systems disrupted most mires before thick peat could accumulate. Fluvial activity became further constrained during accumulation of the uppermost Dunollie, allowing development of relatively widespread, sustained mire conditions.

Table of Contents

Title	i
Abstract	ii
Contents	iii
List of Figures	vii
Chapter One. Introduction	1
1.1 Location of Field Area	1
1.2 Research History of the Greymouth Coalfield	1
1.3 Regional Geology	6
1.3.1 Summary	6
1.3.2 Basement	6
1.3.3 Cretaceous Tectonic Setting	7
1.3.4 Mid-Cretaceous Pororari Group	9
1.3.5 Late Cretaceous – Paleocene Paparoa Coal Measures	10
1.3.6 Paleocene Brunner Coal Measures to Recent	12
1.4 This Project	14
1.4.1 Introduction	14
1.4.2 Objectives	15
Chapter Two. Lithostratigraphy of the Dunollie Fm. and Related Units	17
2.1 History of stratigraphic nomenclature for the Paparoa Group	17
2.2 Paparoa Group Formations, and Brunner Formation	22
Jay Formation	22
Ford Formation	22

Rewanui Formation 24

Morgan Coal Measure Member 24

Waiomo Mudstone Member 25

Rewanui Coal Measure Member 26

Goldlight Formation 27

Dunollie Formation 28

Brunner Formation 29

2.3 Definitions of the Upper and Lower Limits of the Dunollie Formation 30

2.3.1 Goldlight – Dunollie Contact 30

2.3.1.1 Previous Work 30

2.3.1.2 Proposed Goldlight – Dunollie Contact 31

2.3.2 Brunner – Dunollie Contact 34

2.3.2.1 Previous Work 34

2.3.2.2 Proposed Changes to Brunner Stratigraphy 37

2.4 Summary of Proposed Changes 42

Chapter Three. Deposition, Sedimentary Controls 43

3.1 Introduction 43

3.2 Field Work 44

3.2.1 Introduction 44

3.2.2 Field Observations 44

3.2.3 Samples 50

3.3 Drillhole Investigation: Methodology and Rationale 51

3.4 Processing of Drillhole Information 55

3.4.1 Introduction 55

3.4.2 Cross-sections 55

3.4.3 Isopachs 57

3.5 Discussion 61

3.5.1 Goldlight Mudstone Member 61

3.5.2 Goldlight Transitional Member 62

3.5.3 Dunollie Formation 70

3.5.4 Brunner Conglomerate Member and Brunner P 75

3.5.5 Summary and Conclusions 77

Chapter Four. Coal Properties 79

4.1 Introduction 79

4.2 Petrology 80

4.2.1 Introduction 80

4.2.2 Methods 80

4.2.2.1 Sampling 80

4.2.2.2 Petrographic analysis 81

4.2.3 Results 82

4.2.4 Discussion 89

4.3 Chemistry 99

4.3.1 Introduction 99

4.3.2 Methods 99

4.3.3 Results 100

4.3.4 Discussion 104

4.4 Palynology 109

4.4.1 Introduction 109

4.4.2 Method 110

4.4.3 Results 110

4.4.4 Discussion 113

4.5 Synthesis 119

Chapter Five. Summary, discussion and conclusions 124

5.1 Introduction 124

5.2 Coal Occurrence 124

5.2.1 Depositional Setting 124

5.2.2 Mire Occurrence 127

5.2.3 Coal Properties 129

5.2.4 Floral Change 130

5.3 Dunollie Brunner Boundary 131

5.4 Suggestions for Future Work 133

References 135

Acknowledgements 145

Appendix 1: Sampling Locations 147

Appendix 2: Preparation of petrographic polished block mounts 152

Appendix 3: Adjusted Drillhole Data 155

List of Tables and Figures

1.1 Location Map, Greymouth Coalfield. 2

1.2 Stratigraphic column for the Greymouth Basin. 10

2.1 Development of the stratigraphic system for the Paparoa sediments. 19

2.2 Lithostratigraphic summary diagram, Paparoa Group. 23

2.3 Lithologic and geophysical character of the three lithosomes identified within the Paparoa Group. 33

2.4 Proposed stratigraphy for the upper Paparoa Group and Brunner Fm. 37

2.5 Lithostratigraphic summary diagram, Brunner and bounding Formations Greymouth Coalfield. 40

3.1 Study area topographic map and sampling location 46

3.2 Dunollie, Brunner Contact. 47

3.3 "Waterfall" outcrop. 47

3.4 Location of selected Greymouth drillholes 53

3.5 Cross-sections through the southwestern Paparoa Basin 56

3.6 Isopach of the Dunollie Formation. 58

3.7 Isopach of the Goldlight Transitional Member. 59

3.8 Isopach of the Goldlight Mudstone Member. 60

3.9 Tectonic controls active during deposition of the Goldlight Formation. 66

3.10 Proposed evolution of depositional environments from Goldlight MM to Dunollie Fm. 68

3.11 Anastomosing channel deposit from the lower Dunollie, Spring Ck Rd. 71

3.12 Interbedded sandstone and mudstone in the upper Dunollie. 73

3.13 Simplified model of the style and geometry of deposits associated with high sinuosity meandering systems. 75

Table 4.1 Point counts of petrology samples. 83

Table 4.2 Tissue Preservation Indices. 86

4.1 Fluorinite maceral in Dunollie coal. 88

4.2 Resinite maceral showing degradation of margin 90

4.3 Relationships between Tissue Preservation Index and delta Volatile Matter, Cretaceous and Tertiary coals. 92

4.4 Tissue Preservation Indices for plies of seam CN1 93

4.5 Summary of petrologic properties and potential formation environments. 98

Table 4.3 Chemical Data. 101

4.6 Polished sample of weathered coal. 103

4.7 Modified Suggate plot. 105

Table 4.4 Palynology results for the NERF data set. 111

Table 4.5 Additional palynology results. 112

4.8 Percentage of Gleichenia within Brunner P and upper Dunollie seams. 114

4.9 Relative abundance of angiosperms, gymnosperms and spores. 116

Table 4.6 $\delta^{13}C$ and palynology abundance. 117

Table 4.7 Comparative summary of coal properties 119

5.1 Thickness and distribution of the New Point Elizabeth and correlated seams. 128

A1.1 Relative sampling locations. 148

A2.1: Oil contamination of polished block. 154

Chapter 1

Introduction

1.1 Location of field area

Greymouth Coalfield is located at the southern end of the Paparoa Range, northeast of the town of Greymouth, on the West Coast of the South Island, New Zealand (figure 1.1). Sediments making up Greymouth Coalfield range from mid-Cretaceous to Early Tertiary in age, and represent the basin fill deposits of an active tectonic graben system. Greymouth Coalfield represents a substantial resource for New Zealand in terms of high quality, low sulphur and ash, bituminous coal.

1.2 Research History of the Greymouth Coalfield

Early history of Greymouth Coalfield is dominated by mining of workable coal seams throughout the field and is covered in detail in "The Greymouth Coal Field" (Gage 1952). Geologically the concept of the Paparoa Coal Measures dates back to the work of Morgan (1911), who references the 'Paparoa beds' and acknowledges them as distinct and at the time, not correlated with any other coal bearing strata in New Zealand. Morgan (1911) also identified the overlying Brunner Beds as a separate depositional sequence. However it was Gage (1952) who performed the first truly comprehensive investigation of Greymouth Coalfield and its component units. Gage undertook a detailed field survey largely completed between 1938 and 1944. This work culminated in publication of the New Zealand Geological Survey (NZGS), Bulletin 45, "The Greymouth Coal Field" (Gage 1952). The bulletin covered diverse topics, including topographic surveying, geologic mapping, stratigraphic analysis, structural geology and coal properties and resources. Gage's work was an important

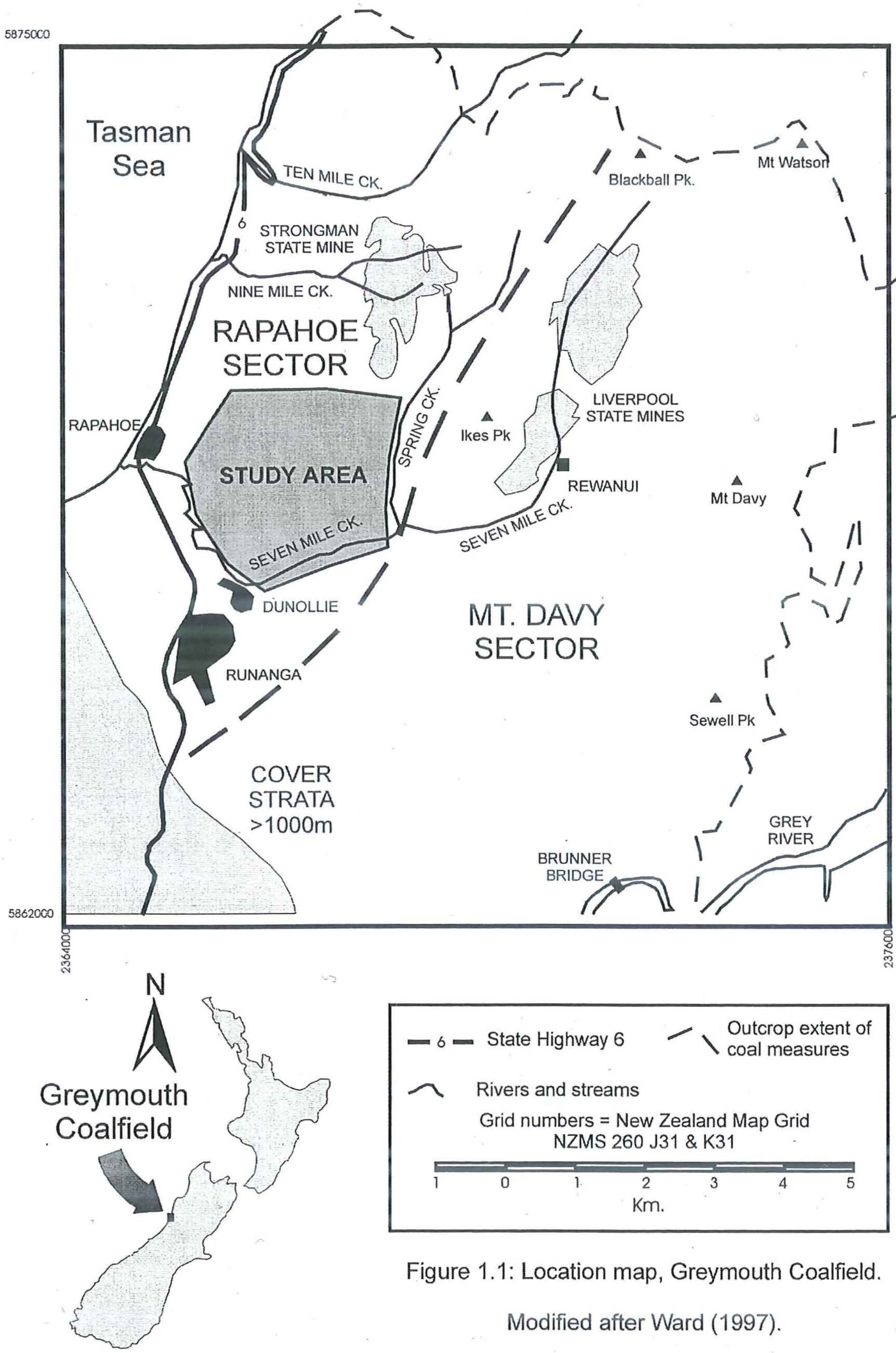


Figure 1.1: Location map, Greymouth Coalfield.

Modified after Ward (1997).

achievement for New Zealand geology, as it not only set a new benchmark for field investigations and reporting, but also formed the foundation for all subsequent work in the region.

Mining and limited exploration continued within Greymouth Coalfield following Gage's work, however most new information about the coalfield came from observations during mining operations rather than dedicated research work. The next major development was the publishing in 1978 of a revised 1:63,360 scale geologic map (Nathan 1978). As part of this work, Nathan reviewed the occurrence, extent and boundaries for major units within the Greymouth Coalfield (Nathan 1974), but for detailed structural and lithostratigraphic information the new map relied on Gage's earlier work. Nathan went on to produce the West Coast volume of the NZGS investigation into late Cretaceous and Cenozoic basins (Nathan et al. 1986).

The next major sequence of investigation took place between 1979 and 1984 when the Mines Division of the Ministry of Energy undertook a study of New Zealand's coal resources producing the Coal Resource Survey (CRS), in order to refine existing resource models and locate new reserves for future development. The CRS at Greymouth included 49 drillholes, drilled on an approximately 1km-grid spacing (Bowman 1982, Bowman et al. 1984). Despite the fact that many of these holes were not fully cored, almost all were geophysically logged and as such the CRS drillhole data set remains a valuable resource for research and modern exploration programs regardless of their objectives.

An initial palynostratigraphic investigation of the Paparoa Coal Measures was completed during the CRS (Raine 1981, 1984). Findings indicated that the

Cretaceous – Tertiary Boundary occurred within the Paparoa Coal Measures but were not expanded upon at the time.

Exploration has continued into the nineties with Solid Energy reviewing and mining the Mt Davy Sector and with continuing exploration and development of Strongman Mine. As well as these investigations, several private operators have continued mining and resource exploration programs in the region. The largest of these and most relevant to this study, is the investigation by Greymouth Coal Operating Ltd. (GCOL). GCOL investigated the potential for underground extraction of coal reserves within the Rewanui Formation over the southern part of the Rapahoe Sector. GCOL carried out significant drilling programs in the Southern Rapahoe Sector, filling gaps in the CRS program and also producing detailed subsurface structural information. Greymouth Coal Ltd (GCL) continues this to the present day. Later investigation focussed on defining viable blocks for extraction and the detailed assessment of coal properties. Currently GCL is engaged in development of mine access, excavating a drive through the Upper Rewanui to their target horizon, and the development of coal blocks for extraction. While a large amount of the GCL data remains confidential due to commercial sensitivity, information from the Dunollie Formation and uppermost portions of the Goldlight Formation have been made available for research purposes.

From the start of CRS exploration to present day, Greymouth Coalfield has seen an increasing number of academic research projects. Initial work mainly examined coal properties and paleoenvironments, resulting in two Ph.D. theses, (J. Newman 1985 and N. Newman 1988). Subsequent work expanded the range of geological fields investigated, providing many insights into the nature and development of the Paparoa basin and associated sediments. These have included sandstone diagenesis (Boyd 1993), structural geology (McNee 1997) and palynology (Ward et al 1995; Moore 1996a,b). Of special relevance is the Ph.D. thesis of Simon Ward (1997), which examined the environment of, and controls on deposition of the Paparoa Coal Measures. In this major undertaking Ward upgraded the unit hierarchy of the Paparoa Coal Measures members and defined a new set of guidelines for determining unit boundaries based on the geophysical logs that make up the bulk of the data set available for the Greymouth Coalfield.

1.3 Regional Geology

1.3.1 Summary

Rocks that make up the basement of Greymouth Coalfield and the overlying sediments have been located on or near a plate boundary since at least the Lower Palaeozoic. This location, and resultant tectonic controls, influenced the development of the later sedimentary groups. Erosion of exposed basement rocks followed by deposition in rapidly subsiding fault controlled basins, formed the overlying sedimentary cover constituting Pororari Group and Paparoa Coal Measures (Nathan et al 1986). These basins formed as a result of listric faulting, associated with spreading and deformation of the New Zealand continental block during separation from Gondwana and opening of the Tasman Sea (Laird 1992). Basin development by extensional processes produced a 5% regional extension (Bishop and Buchanan 1995).

1.3.2 Basement

Basement at Greymouth Coalfield comprises "Paleozoic Greenland Group greywacke, and argillite" Nathan (1978). Greenland Group sediments formed as an accretionary wedge on the convergent margin of Gondwana. Sedimentation was dominantly the product of turbidite activity driven by the transport of weathered sediments off the Gondwana continental block (Nathan & Roser 1996, Roser et al 1996).

Although of a massive and relatively undifferentiated appearance in the field the Greenland Group can be divided into three parts based on the changing chemical composition of sediments of igneous provenance (Roser et al., 1996). Biostratigraphic control within the Greenland Group is scarce. Only one Graptolite specimen, of early Ordovician age, has been reported (Cooper 1989).

The Greenland Group has undergone major internal folding and faulting. With deformation occurring during the Early Silurian when the Greenland tectonic event disrupted and deformed all the deposits within the province. The only basement sediments found postdating this tectonic event are the locally deposited Reefton Group of Lower to Middle Devonian (Nathan et al 1986).

Granitic intrusion into basement sediments occurred during the Middle-Devonian. This suite of granitoids of the Karamea Batholith, intruded approximately 370 ± 5 Ma. (Muir et al., 1994). Windy Point Granite and the Cape Foulwind Granite were formed in a separate Palaeozoic intrusive event (~330 Ma.) (Muir et al 1992, Muir et al 1994). Both this event and the Karamea suite can be linked to episodes of granitic intrusion in both Antarctica and Australia at similar times. This would indicate that the intrusion of granitic magmas was a regional Gondwana event and not limited to the rocks of the New Zealand Western Province. The widespread intrusion of these granitoids throughout the Greenland Group makes them one of the dominant rock types of the West Coast basement. These granitic intrusions are important, as the weathering and erosion of granite is a major source of sediment for sedimentary deposits through to present day.

1.3.3 Cretaceous Tectonic Setting

The regional system of Mesozoic Gondwana convergent margin tectonics accelerated in the Cretaceous, thickening and deforming the Greenland Group accretionary wedge (Bradshaw, 1989). Associated intrusion of a suite of granitic bodies occurred between 120-110 Ma. These granitic bodies show a younging relation towards the west, from the Pearse Granodiorite in the east, which forms part of the Separation Point Batholith (119.4±2.3 Ma.), to the Buckland Granite in the west (109.6±4.4 Ma.) (Muir et al. 1994).

These episodes of intrusion were the precursor to the break up of Gondwana and the opening of the Tasman Sea. These Mesozoic granitic events, like those of the Mid-Palaeozoic, have parallels in Marie Byrd Land and central Queensland (Weaver et al 1996).

The tectonic setting abruptly changed at 105±5 Ma from the convergent system that had dominated since the Permian to an extensional regime (Bradshaw 1989). This abrupt change is believed to have been caused by convergence of the trench associated with the Pacific-Phoenix plate boundary and the Gondwana boundary (Bradshaw 1989, Bradshaw et al 1993). This collision destabilised the Gondwana continent and the resulting extensional regime rifted away the New Zealand continental block from the Antarctic and Australian segments of Gondwana.

The rifting model proposed by Tulloch & Kimbrough (1987) for the separation of New Zealand is the Wernicke model of simple shearing detachment producing metamorphic core complexes and associated basins. First the two plates separated on a zone of large-scale, listric normal faulting orientated WNW – ESE. As separation continued, the hanging wall of the boundary became divided into block segments by a progressive sequence of incipient listric normal faults. At the same time the deeper regions of the boundary began deformation by ductile shearing and attenuation producing the mylonitized rocks that outcrop on the present day coast south of Morisly Creek, as the basal section of the Charleston metamorphic core complex. The pre-separation intrusion of the granitoids formed a precursor to an upwelling within the asthenosphere at the plate margin, uplifting the thinned crust and accelerating separation of the two plates. This accelerated separation split up blocks formed from the hanging wall above, rotating them into the plane of extension. At this time (109 Ma.) the Berlin Quartz Porphyry was intruded into the deforming basement. The Antarctic-Australia plate section continued to pull away. At about 82 Ma this process formed what would later become the Tasman Sea extensional ridge (Laird 1992).

The final result of the separation from Gondwana was a New Zealand continent that had been thinned and uplifted. There formed a series of well developed fault bounded basins or grabens, surrounded by blocks of structurally higher basement, that continued to develop up to 85 Ma.

1.3.4 Mid-Cretaceous Pororari Group

Sedimentation in the extensional basins occurred whilst the breakup continued. The first sediments constituting the Pororari Group, were deposited at approximately 105 Ma, and unconformably overlie basement (figure 1.2). The lowest Pororari Group formation is Stitts Tuff, however this does not occur in the Greymouth area. Instead, the Hawks Crag Breccia directly overlies basement (Nathan 1978), deposited by rapidly growing alluvial fans from the higher faulted basement blocks into two major syntectonic basins. The unit generally comprises a series of thickly bedded coarse breccias with limited sandy horizons (Gage 1952). The development of fluvial systems away from the source areas in the basins created the other major unit of the Pororari Group, the Ohika Beds. These deposits comprise progressively finer fluvial sediments away from the basin margins, interbedded with limited lacustrine deposits representing small lakes (Nathan et al 1986). There is a break of 15 Ma in the sedimentary record at 85 Ma following the end of major extension at 95 Ma.

Within Greymouth Coalfield there are areas where the mid-Cretaceous Pororari Group is absent, and Late Cretaceous – Paleocene Paparoa Coal Measures lie directly on basement. The Pororari Group was either eroded before Paparoa Coal Measures sedimentation commenced, or was never deposited in these areas.

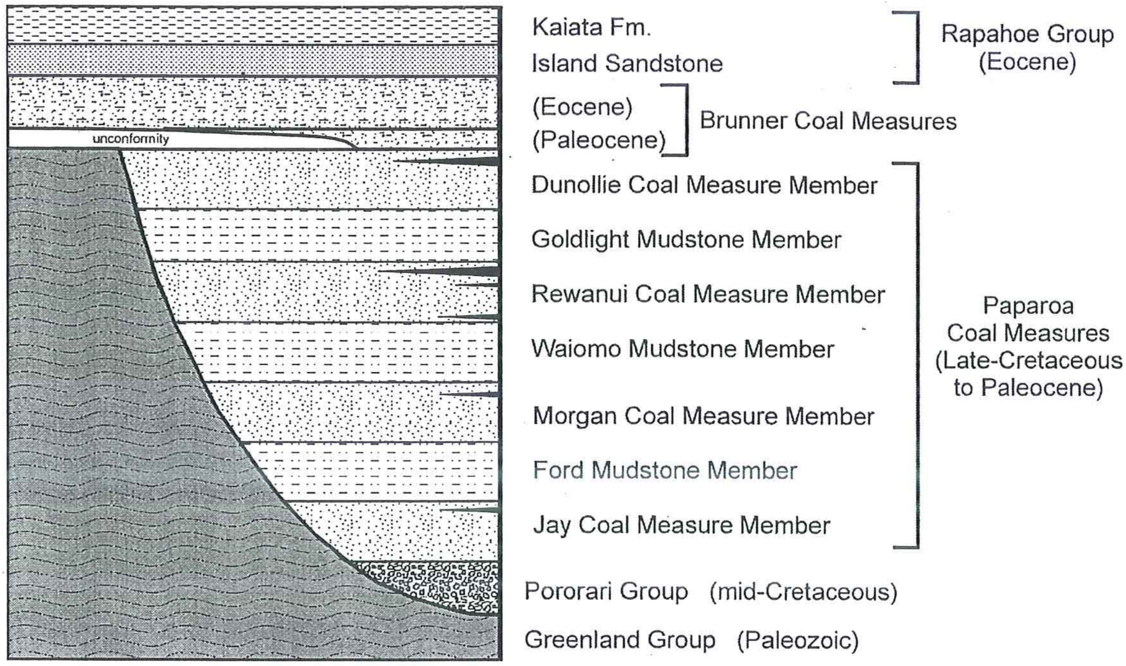


Figure 1.2: Stratigraphic column for the Greymouth Basin

After Nathan (1978); Newman & Newman (1992)

1.3.5 Late Cretaceous – Paleocene Paparoa Coal Measures

After a break in the sedimentary record of 15 Ma or more, the regional pattern of WNW – ESE listric faults again became active due to movement away from the upwelling Tasman spreading ridge and the associated subsidence of the New Zealand landmass (Laird 1992). This produced a narrow fault controlled graben at the site of Greymouth Coalfield, the margins of which were not likely to have been more than 12 km apart (Newman & Newman 1992). This represented the beginning of the more localised depositional sequence that makes up the Greymouth Coalfield (figure 1.2). Continued listric faulting throughout the basin's life produced a pattern of subsidence focused on the basin's axis, where the greatest thickness of sedimentary material accumulated. Sediment transport and deposition within the basin were controlled by a southward flowing axial river system flanked by alluvial fans fronting the fault bounded margins (Gage 1952). Sediments within the basin can be divided into a western compositional suite, which is dominantly Greenland Group derived, and an eastern compositional suite of granitic character (Newman & Newman 1992; Boyd & Lewis 1995).

Paparoa Coal Measures are divided into seven members; four fluvial units, separated by three lacustrine mudstones (figure 1.2) (Gage 1952; Nathan 1978). Due to the nature of sediment supply and the shape of the basin, not all of the Paparoa Coal Measures component members are found at every location across the basin.

Greywacke conglomerate at the base of the Jay Coal Measure Member overlies the more angular red greywacke breccia of the Hawks Crag Breccia. There is a marked and sudden change in colour and rounding, but otherwise no sign of a major break (Nathan 1974), although 15 m.y. are inferred to have elapsed between deposition of the two units. The upper part of the Jay Coal Measures comprises grey or grey-brown sandstone, carbonaceous shale, greywacke conglomerate, and scattered coal seams (Nathan 1978). Separating the Jay Coal Measures from the Morgan Coal Measures is the Ford Mudstone Member, which is a light to dark grey micaceous sandy mudstone. The Morgan Coal Measures overlie the Ford Mudstone and closely resemble the upper portion of the Jay Coal Measures. Morgan Coal Measures are therefore distinguished in the field based on position relative to the Ford Mudstone Member.

The Waiomo Mudstone Member, a massive dark brown to brown-grey micaceous mudstone, separates Morgan Coal Measures from the Rewanui Coal Measures (figure

1.2) (Nathan 1978). Rewanui Coal Measures consist of lensoid bodies of medium to coarse white, light yellow, or light brown quartz-mica sandstone. Sandstone lenses are interbedded with comparatively thin layers of dark-brown or grey carbonaceous mudstone and coal seams (Gage 1952). In terms of mining, both historically and present day, the Rewanui Coal Measures contain some of the most important coal seams of the Greymouth Coalfield.

With the exception of the northwestern portion of the Paparoa basin, the Goldlight Mudstone Member overlies the Rewanui Coal Measures (Nathan 1978). The Goldlight Mudstone Member is another massive grey-brown to grey micaceous mudstone. Fragmented leaf remains are common near the base of the member, while the upper portions contain sandy horizons that grade conformably into the overlying Dunollie Coal Measures (Gage 1952, Nathan 1978).

The uppermost member of the Paparoa Formation is the Dunollie Coal Measures. Dunollie Coal Measures are very similar in appearance to the Rewanui Coal Measures, however the Dunollie Coal Measures are more quartzose and uniformly bedded. Dunollie Coal Measures represent the final infilling of the Paparoa Basin in the late Palaeocene. Cessation of deposition can be related to the end of spreading in the Tasman Sea (~60 Ma.). The deposits overlying the Paparoa Formation are generally thinner and occur on a more regional scale (Newman 1985).

1.3.6 Paleocene Brunner Coal Measures to Recent

The Brunner Coal Measures overlie the Paparoa Formation and extend far beyond the boundaries of the Late Cretaceous Paparoa Basin. Brunner sediments occur south of Hokitika and north into the Nelson region (Nathan et al. 1986). The Brunner consists of a series of interbedded quartz rich sandstones and conglomerates with occasional and, in some areas, exceptionally thick coal seams. The Brunner commonly rests upon deeply leached older sediments or basement (Gage 1952). This leaching is thought to represent a significant hiatus between deposition of the tectonically confined Paparoa Group and the commencement of a more regional depositional system in the Eocene (Nathan 1978). However, in the centre of the Greymouth basin, the Brunner Coal Measures are apparently conformable with Dunollie Coal Measures (Newman 1985, Raine 1984). The Brunner Coal Measures represent the first of the major units associated with the Tertiary marine transgression (Nathan 1978). Deposition occurred in a widespread fluvial system bounded by an encroaching marine facies.

Overlying the Brunner Coal Measures is a sequence of marine and marginal marine sediments deposited from Eocene to Oligocene, comprising the Rapahoe and Nile Groups (Nathan 1974). Lever (1999) suggests that the Brunner Coal Measures should be included in the Rapahoe Group, as it represents the first sediments deposited in the Palaeocene to Neogene marine transgression of New Zealand. This suggestion is examined in Chapter 2 along with the relationship between the Brunner Coal Measures and underlying members. Resting conformably upon the Brunner Coal Measures is the Island Sandstone. The Island Sandstone is a shallow marine, inner shelf deposit comprising a brown-grey, fine to very fine muddy sandstone (Lever 1999). Kaiata Formation conformably overlies the Island Sandstone, and consists of a well sorted, dark grey glauconitic, calcareous sandy mudstone. Other members of the Rapahoe Group may have been deposited at Greymouth Coalfield however, erosion has removed this sequence from all but the western, southern, and eastern margins of the coalfield (Ward 1997). Within the study area, Island Sandstone occurrences are common as a thin cap above the Brunner Coal Measures, while Kaiata Formation is restricted to the western margin.

The Paparoa basin and associated sediments were uplifted and exposed by Neogene to Recent compressional tectonics (Nathan et al 1986). This compression reactivated the regional pattern of listric faults, deforming and inverting the basin (Bishop & Buchanan 1995). The Paparoa Group currently forms a south-southwest plunging anticline. Reactivation of the Cretaceous – Palaeocene fault systems has resulted in Greymouth Coalfield being highly faulted by a combination of reverse and normal faults, with displacement of fault blocks by throws commonly up to 100m (McNee 1997). Coaly horizons within the coal measues have provided a focus for shearing, with slickensiding associated with most coaly or carbonaceous horizons (Ward 1997, McNee 1997). Disruption is common within vertical sequences, with whole units repeated or absent altogether due to faulting and shearing.

1.4 This Project

1.4.1 Introduction

The Dunollie Coal Measures consists of a rare Palaeocene terrestrial sequence, allowing an uncommon insight into the climate and flora of post-Cretaceous New Zealand. This is an important location for paleoenvironmental investigations, as terrestrial deposition on the New Zealand continental block at this time was very limited (Nathan et al 1986). Dunollie Coal Measures within the Southern Rapahoe Sector is also unusual in that numerous coal seams of variable character occur in close stratigraphic proximity, while elsewhere the Dunollie is devoid of coal occurrences (Gage 1952). The Southern Rapahoe Sector also has the advantage that outcrop information is supported by a large number of drill holes from both the CRS and GCOL exploration programs. Drilling in the region has produced geophysical data, physical core and chip logs.

1.4.2 Objectives

This research project aims to determine the reason for coal occurrences in the Dunollie and for the high degree of variability in seam characteristics and coal properties. To this end it is necessary to integrate information on floral and climatic changes (FRST program CRA 802) with the lithostratigraphy, coal petrology and chemistry.

Another goal is to provide a workable boundary between the Dunollie Coal Measures and Brunner Coal Measures, which conformably and cryptically overlies the Dunollie throughout the Southern Rapahoe Sector.

To achieve these objectives the following investigations were undertaken:

- Ground investigation to determine the extent of coal occurrence within the Dunollie in the Southern Rapahoe Sector.
- Review of the current stratigraphic system for the Goldlight, Dunollie and Brunner Members.
- Collection of samples from the Dunollie coal seams, for both petrologic and chemical analysis.
- Examination of coal properties including petrology and chemistry.

- Review and integration of palynology that has been completed for the Dunollie Formation coals.
- Lithostratigraphic review of the Dunollie and related units, including cross-sections and isopachs.
- Interpretation of relationships between coal properties in terms of depositional controls.
- Development of a coal measures depositional model and a model of mire environment.

Chapter 2

Lithostratigraphy of the Dunollie Formation and related units

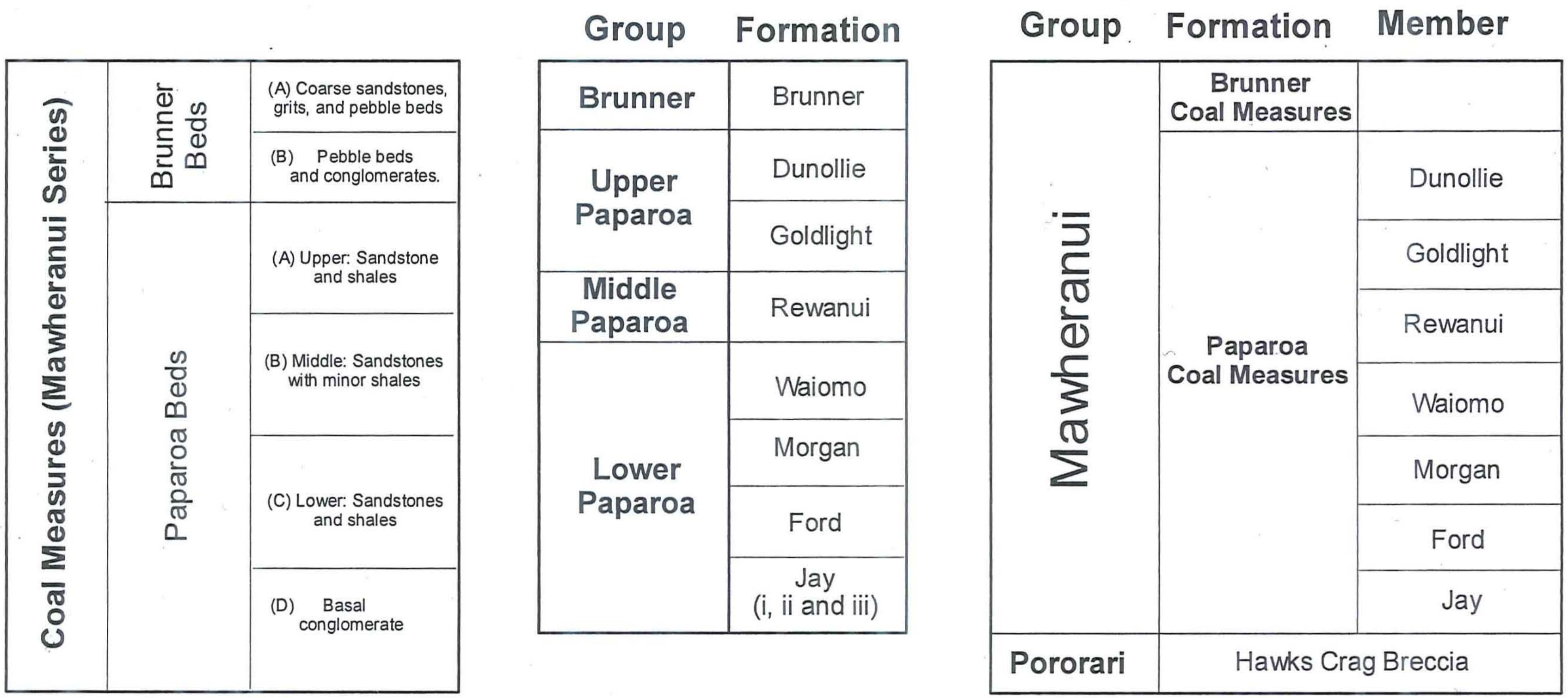
2.1 History of stratigraphic nomenclature for the Paparoa Group

Identification of the Paparoa basin sediments as a grouped entity originates in "The Geology of the Greymouth Subdivision, North Westland." N.Z. Geological Survey Bulletin 13 (Morgan 1911). Morgan recognised a sedimentary sequence "comprising basal conglomerate, succeeded by Lower Paparoa Beds (sandstones and shales), Middle Paparoa Beds (sandstones with minor shale) and Upper Paparoa Beds (sandstones and shales)" (Morgan 1911) (Figure 2.1 A). Revision of the stratigraphy of the Paparoa basin became a major focus of the NZGS survey of the Greymouth Coalfield (Gage 1952). Gage recognised a sequence of generally sandy coal bearing units, divided by a set of coal deficient, mud rich units. Gage attributed this sequence to a depositional system alternating between fluvial and lacustrine conditions. Gage named the four coal bearing fluvial units Jay, Morgan, Rewanui and Dunollie. The intermediate lacustrine units he labelled Ford, Waiomo and Goldlight. Gage assigned the title of formation to each of these sedimentary packages, with each of the formations defined in terms of their lithology and the relationship shared with bounding formations (Gage 1952 pp. 20-39). Each formation was then placed within a group, the names and concepts for which were derived from Morgan's earlier stratigraphic system (Figure 2.1 B).

Nathan (1978) then re-examined and redefined the hierarchy of the Paparoa Basin. Nathan downgraded the various Paparoa Groups to a single formation and combined this new Paparoa Formation with the overlying Brunner Formation, under the heading

Mawheranui Group. The formations of Gage were redefined as members, using the titles Coal Measure Member (CMM) or Mudstone Member (MM) (Figure 2.1 C). Nathan also removed the lowest division of the Jay CMM (Gage's Jay i), placing it instead within the Pororari Group as part of the Hawks Crag Breccia.

Two further adjustments to the stratigraphic nomenclature of the Paparoa basin occurred during the 1980's. First was the division of the Brunner Coal Measures at Greymouth into two units, one Palaeocene in age and the other Eocene (Newman 1985). Newman also correlated the Paparoa Coal Measure Members with equivalent units at Pike River Coalfield. The second adjustment occurred with the rejection of the Mawheranui Group (Laird 1988). Laird rejected the placement of the Brunner Formation and Paparoa Formation into a single group, due to the generally unconformable nature of the contact between the Paparoa Coal Measures and Brunner Coal Measures.



A. Morgan (1911) B. Gage (1952) C. Nathan (1978)

Figure 2.1 Development of the stratigraphic system for the Paparoa sediments

(A) Original division of the Paparoa Beds (Morgan 1911). (B) Division of the Paparoa Groups and definition of the seven component formations (Gage 1952). (C) Revision of stratigraphic hierarchy, downgraded Paparoa Groups into a formation, revision of the formations (Gage) into members (Nathan 1978)

Ward (1997) provides the most recent revision of stratigraphy for the Paparoa basin. Ward reclassified all of the Paparoa sediments into a Paparoa Group, which "encompasses the coal measures and intercalated mudstone units found beneath the quartzose Brunner Coal Measures within the Greymouth Coalfield". Ward then reclassified each coal measure member (CMM) or mudstone member (MM) based on the nature of its occurrence and distribution within the Greymouth Coalfield. The Jay CMM, Ford MM and Dunollie CMM all became classified as formations in their own right. The Morgan CMM, Waiomo MM and the Rewanui CMM all remained as such, however they were assigned as members into a newly defined Rewanui Formation. The Goldlight MM is also elevated to Formation status, however the new Goldlight Formation consists of both the traditional Goldlight MM and a Goldlight Transitional Member.

Transitional Member is a new division of the Paparoa sediments introduced by Ward (1997 pp.31). The addition of the transitional members to the division of the Paparoa Group was based on their distinctive geophysical signature, and Ward's interpretation that the transitional members represented a different depositional environment from that of normal lacustrine sedimentation. Ward defined the transitional members in terms of lithosomes consisting of interbedded mudstones, siltstones and moderately sorted to well sorted, very fine to medium sandstones, with some rare carbonaceous material. Beds range in thickness from 2-20m and soft sediment deformation is common. Geophysical logs show coarsening-upwards packets either with a funnel shaped log motif, or a serrated log motif. These transitional lithosomes are interpreted as representing a lacustrine delta environment (subaqueous, rarely emergent) (Ward 1997).

Problems remain however, with the lithostratigraphic classification of some formations present at Greymouth. The Brunner Coal Measures and Brunner Formation are currently not assigned to any satisfactory Group, because the other Tertiary deposits to which authors have previously assigned the Brunner are of too limited distribution to be comparable with the relatively widespread Brunner Formation (Ward 1997).

The following section describes the formations in detail. The division of formations and the assignment of members within the formations are after Ward (1997) with reference to Nathan (1978) for the Brunner Formation. The section then proposes some modifications to Ward's (1997) stratigraphic system. Changes are also proposed to the stratigraphy of units above those examined by Ward (1997), these proposals deal with the upper Dunollie and overlying Brunner Formation.

2.2 Paparoa Group Formations, and Brunner Formation.

The relationship and occurrence of the formations that make up the Paparoa Group are summarised in figure 2.2 (Ward 1997). A detailed description of each unit and its relationship to basement and the bounding units is provided below.

Jay Formation: (Gage 1952)

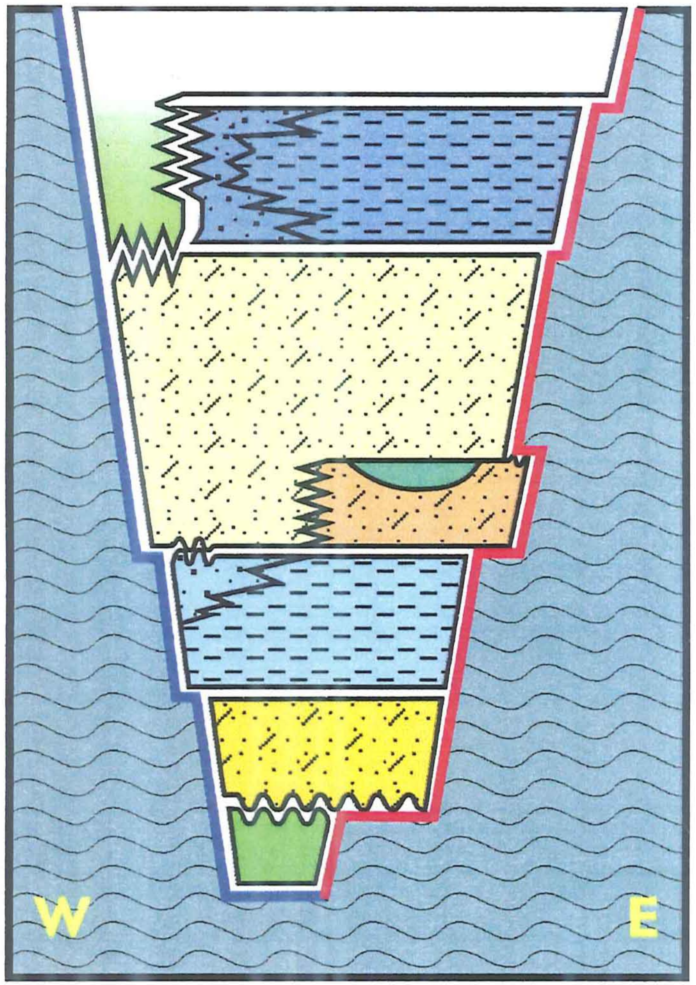
DISTRIBUTION: Outcrop occurs primarily in the northern section of the Greymouth Coalfield, along the coast around Twelve Mile Creek and in Ten Mile Valley. Jay Formation is thickest south of Blackball Peak, forming a lens of material orientated WNW-ESE, with a maximum inferred thickness of ~140m (Gage 1952; Ward 1997).

DESCRIPTION: Jay Formation comprises the Jay (ii) and Jay (iii) units of Gage (1952). Lower Jay Formation is made up of a sandy conglomerate which grades upward into a well bedded grey or brown-grey sandstone, containing lenses of coarser basement derived material. Coal seams occur only in the upper part of the Jay Formation.

STRATIGRAPHIC RELATIONS: The formation rests in unconformable contact on the Hawks Crag Breccia, the Jay (i) unit of Gage (1952) being assigned to the Pororari Group. Elsewhere the Jay Formation directly overlies basement.

Ford Formation: (Gage 1952)

DISTRIBUTION: Ford Formation occupies a broad NW – SE orientated trough, which divides eastward into two depocenters separated by a zone of thinning beneath Mt. Davy (Ward 1997). Mudstone exposures at Twelve Mile Beach previously assigned to Waiomo Formation by Gage (1952) and Nathan (1978) are now included as part of Ford Formation (Ward 1997). The Ford Transitional Member occurs south of Ten Mile Creek and generally to the west of Seven Mile Creek. The Ford Transitional Member



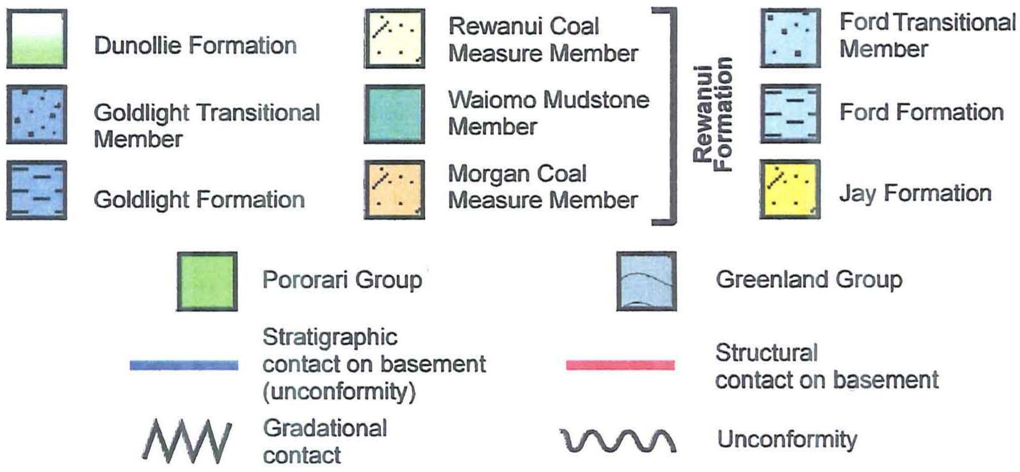


Figure 2.2: Lithostratigraphic summary diagram,
Paparoa Group, Greymouth Coalfield.
Exploded view showing relationships between Formations and Members.
(not drawn to scale)
Copied with permission from Ward (1997)

is poorly constrained east and south of Rewanui, due to limited outcrop and drillhole data.

DESCRIPTION: Ford Formation consists of a dark-brown to brown-grey micaceous siltstone interbedded with fine bands of light-grey sandstone (Gage 1952; Nathan 1978). The northeastern portion of the Ford Formation contains volcaniclastic lithofacies, comprising volcanic conglomerate and tuffaceous sandstone (Nathan 1978). These volcanic sediments are not assigned a specific stratigraphic name due to their discontinuous distribution (Ward 1997). Ford Formation reaches a maximum thickness (~180m) in the upper reaches of Spring and Nine Mile Creeks (Ward 1997).

STRATIGRAPHIC RELATIONS: The Ford Formation rests conformably upon the Jay Formation. Where the Jay Formation is absent the formation rests directly upon basement. In the west the Ford Formation grades upward into the Ford Transitional Member, which generally contains a greater number of sandy interbeds.

Rewanui Formation (Gage 1952)

Comprises three Members, Rewanui CMM, Waiomo MM and Morgan CMM.

Morgan Coal Measure Member (Nathan 1978)

DISTRIBUTION: The member is now considered to be restricted to a region around Mt. Davy and Rewanui (Ward 1997). Deposition was centered on two parallel zones, one in the upper portion of Seven Mile Creek, and the other around Mt. Davy. An inferred maximum thickness of ~80m was deposited in these basins (Ward 1997). In the east the addition of volcanic material to the Morgan increases the members thickness to ~120m, far less than the 1500ft/450m indicated by Gage (1952) for this area. A small basin of deposition also occurred to the south in the area of Brunner Bridge. Exposures assigned by Gage (1952) to Morgan Formation in Ten Mile and Twelve Mile Creeks, have been transferred by Ward (1997) to Jay Formation.

DESCRIPTION: Dominantly fine grey sandstone, interbedded with minor carbonaceous mudstone and coal, make up the Morgan Coal Measure Member (Ward 1997). In the east basaltic volcanic material is interbedded with the Morgan Coal Measures, significantly increasing the overall unit thickness (Gage 1952; Nathan 1978; Ward 1997).

STRATIGRAPHIC RELATIONS: The Morgan Coal Measure Member overlies Ford Formation at a sharp well-defined contact. However on the eastern flanks of Mt Davy the Morgan Coal Measures lie directly upon basement (Caffyn 1994). This is also the southern limit of known outcrop. Due to the poor outcrop most information on the Morgan CMM is derived from drillholes.

Waiomo Mudstone Member (Nathan 1978)

DISTRIBUTION: Waiomo MM occupies a broad shallow basin, from Spring Creek east to Mt. Davy. The southern boundary occurs north of Sewell Peak and the basin runs north to Blackball Peak. The Waiomo MM reaches a maximum thickness of ~50m south of Blackball Peak (Ward 1997). Exposures in Ten Mile Valley and at Twelve Mile Beach which were previously classified as Waiomo (Gage 1952; Nathan 1978) are now included in the Ford Formation (Ward 1997).

DESCRIPTION: The Waiomo comprises a massive dark-grey to grey-brown, micaceous mudstone, with rare sandstone or siltstone interbeds (Gage 1952; Ward 1997).

STRATIGRAPHIC RELATIONS: Waiomo MM is conformable with the overlying Rewanui Coal Measure Member and underlying Morgan Coal Measure Member. Ward (1997) recorded some rare transitional lithosomes at the base and top of the Waiomo MM. However, Ward was unable to define the extent of these transitional lithosomes, and poor drillhole records did not allow these to be subdivided into a separate stratigraphic unit.

Rewanui Coal Measure Member (Nathan 1978)

DISTRIBUTION: The Rewanui CMM is present across most of the Greymouth Coalfield. Two distinct basin orientations are present within the Rewanui CMM. The dominant basin axis is aligned NNE – SSW delineated by the sharp eastern margin and the region south east of Runanga. A second basin alignment is present in the Rapahoe Sector with the local depocentre orientated NW – SE (Ward 1997). Generally thick throughout the basin the Rewanui CMM has a maximum thickness of ~250m. The eastern side of the basin is marked by a rapid decrease in thickness, with the Rewanui Coal measures wedging from >200m to nothing in the space of 1km. The southwestern basin margin is far more gradual. Thinning of the Rewanui CMM commences around Ikes Peak and continues to the southwest, wedging out under Runanga.

DESCRIPTION: Generally the Rewanui consists of medium to coarse, white to light yellow, micaceous sandstone, separated by thin carbonaceous mudstone horizons and coal seams (Nathan 1978). Cross-bedding and lenticular bedding are common within the light yellow sandstone horizons, while the grey-green sandstones range from massive to bedded.

STRATIGRAPHIC RELATIONS: In the western portion of the coalfield the Rewanui CMM is in contact with transitional lithosomes of the Ford Formation. In the east the Rewanui CMM overlies the massive mudstones of the Waiomo (where present) or the Morgan CMM (Caffyn 1993). In the southwest the Rewanui CMM directly overlies basement.

Goldlight Formation (Gage 1952)

DISTRIBUTION: The Goldlight Formation lies within a NE – SW trending basin. The abrupt eastern margin is in line with Mt. Watson and Sewell Peak, while the western margin lies parallel to the modern coastline. Goldlight Formation is most variable in thickness in the Southern Rapahoe Sector. This apparent complexity may however be an artefact of the data set, as a greater number of drillholes exist in this region, allowing the Goldlight to be defined more precisely. In the western and southern portions of Greymouth Coalfield the Goldlight Formation contains a transitional member, and in a narrow western zone the transitional member comprises the full Goldlight thickness. Away from the western margin the transitional member occurs in two parts, an upper Goldlight Transitional Member which occurs between the lacustrine Goldlight and the Dunollie Formation, and a lower Goldlight Transitional Member between the lacustrine lithosomes and the Rewanui CMM.

DESCRIPTION: The Goldlight Formation comprises massive, dark grey-brown silty mudstone. Goldlight mudstone lithosome differs from the other mudstones within the Paparoa Group as it is extremely uniform over great thickness (Ward 1997). Where transitional lithosomes are present they comprise interbedded mudstones, siltstones and moderately to well sorted, very fine to medium sandstones, with some rare carbonaceous material.

STRATIGRAPHIC RELATIONS: Goldlight Formation overlies Rewanui CMM. Generally the contact is marked by an abrupt change from sandstone to massive mudstone. In the west the contact is transitional in nature with the inclusion of transitional lithosomes between the lacustrine Goldlight and the Rewanui CMM.

Dunollie Formation (Gage 1952)

DISTRIBUTION: Dunollie Formation covers a wide area in the central part of the Greymouth Coalfield. There is limited exposure north of Ten Mile Creek where the Goldlight Formation is absent and the Dunollie and Rewanui Formations form a continuous sequence, the boundary between which is poorly defined (Ward 1997). Like the formations below, the Dunollie Formation thins rapidly at the eastern margin of the basin. In the south and southwest the plunging Paparoa Anticline reduces outcrop south of Seven Mile Creek, but drillhole information indicates that the Dunollie occurs as far south as Dobson (Gage 1952).

DESCRIPTION: Generally fine to coarse, grey-white to grey-brown sandstone beds, interbedded with light to dark grey siltstone, mudstone and carbonaceous shale. Sandstone beds range in thickness from a few centimetres to greater than three meters (Nathan 1978). Carbonaceous material is common throughout the Dunollie Formation, however thick coals are restricted geographically to the Dunollie area and then only in zones near the top and bottom of the formation (Gage 1952). The Dunollie coarsens in the northwest grading laterally into a greywacke conglomerate. In the area around Spring Creek the uppermost Dunollie consists of greywacke conglomerates that become increasingly quartzose and grade into overlying Brunner conglomerate.

STRATIGRAPHIC RELATIONS: In the southern portion of Greymouth Coalfield the Dunollie Formation overlies lithosomes of the Goldlight Transitional Member. In the northwest around Ten Mile Creek and on the western margin of the basin the Goldlight Formation is absent and the Dunollie and Rewanui Formations are conformable (Ward 1997). On the eastern margin of the basin area around Sewell Peak the Dunollie Formation rests directly on basement Greenland Group (Nathan 1978).

Brunner Formation (Morgan 1911)

While not part of the Paparoa Group the Brunner Formation is included here due to the relationship it shares with the Dunollie Formation. Also it is proposed later in this chapter, that part of the Brunner material at Greymouth be included into the Paparoa Group.

DISTRIBUTION: Brunner Formation extends well beyond the Greymouth Coalfield with Brunner sediments reported south of Hokitika and north into the Nelson region (Nathan et al. 1986). Within the Southern Rapahoe sector Brunner Formation occurs as a collection of discreet caps on hill and ridge tops. Most Brunner Coal Measures are dated at Mid to Late Eocene, however at Greymouth a Paleocene aged unit Brunner (P), has been identified (Nathan, et al 1986).

DESCRIPTION: Generally fine to coarse interbedded quartz sandstone containing some limited micaceous material. In the study area the lower Brunner is made up of quartz conglomerate with minor greywacke clasts that is in gradational contact with the underlying greywacke dominated Dunollie conglomerate (Gage 1952). Coal occurrence is rare, limited to seams in the vicinity of Trig K No.3 and on the ridge crest west of the New Point Elizabeth Mine.

STRATIGRAPHIC RELATIONS: In the central portion of the Greymouth Coalfield the Brunner Formation is in gradational contact with the Dunollie Formation. In coastal exposures the Brunner and Dunollie conglomerates are divided by a weathered unconformity (Gage 1952, Nathan 1978). Island Sandstone succeeds the Brunner Formation in a conformable succession (Gage 1952).

2.3. Definitions of the Upper and Lower Limits of the Dunollie Formation

In the present study, an approach similar to that of Ward (1997) has been adopted for proposing the location of Dunollie Formation boundaries, in order to develop a system which is consistent with the division of other Paparoa formations.

2.3.1 Goldlight – Dunollie Contact

2.3.1.1 Previous Work

Ward's (1997) investigation of available lithostratigraphic resources led him to conclude that the Greymouth Coalfield geophysical database provides the most accurate and consistent division of sediment type (sandstone, mudstone or carbonaceous material) throughout the Greymouth Coalfield. This information was collected as part of the Coal Resources Survey (CRS) and Greymouth Coal Ltd (GCL) drillhole surveys. Ward tackled the problem of boundary divisions between Paparoa Group members, with particular emphasis on making the new boundaries discernible from geophysical logs. Ward developed a series of lithosome models, from the geophysical data set, with comparison to drillhole core. Each of these lithosomes represented one of three phases of sediment deposition within the Paparoa Group (mudstones, coal measures and transitional lithosomes).

From the above concepts Ward redefined the boundary between the Goldlight and the Dunollie as being the highest occurring transitional lithosome within the Paparoa Group and as such a sub-member of the Goldlight Formation (Figure 2.2). Defining the lower Dunollie boundary as lying above transitional lithosomes of the Goldlight Formation (Ward 1997) was also an improvement in terms of a working field definition. However work remained in applying this definition to examining the detailed nature of the Goldlight - Dunollie contact, which was beyond the scope of Ward's thesis.

2.3.1.2 Proposed Goldlight – Dunollie Contact

Since its inception by Gage (1952), Dunollie Formation has been described in terms of fluvial dominated sandstones containing carbonaceous material or coal with some mudstone/siltstone beds. Ward defined Coal Measure Lithosomes with specific reference to the necessity of carbonaceous material (Ward 1997 p.14). In this context, and given the lack of a distinctive lithologic break, the base of the Dunollie is redefined in terms of the first occurrence of sustained carbonaceous material in association with an absence of lacustrine mudstones. The lower boundary therefore lies above a series of interbedded sandstones and mudstones belonging to the Goldlight transitional lithosomes.

Where outcrop or core data are unavailable for physical inspection, the occurrence of carbonaceous material can sometimes be determined from geophysical logs. Location of the boundary using geophysical data is desirable, as very little Dunollie core has been preserved from the CRS drilling program and most GCL drillholes cored little or no Dunollie – Goldlight sediments. Fortunately, full geophysical logs were made for most drillholes, although some drillholes from the initial phase of GCL exploration were only logged for gamma response.

A key feature for lithosome determination is that the carbonaceous beds result in a strong 'kick' to the left (low readings) for both gamma and bulk density geophysical logs (figure 2.3, after Ward 1997). Caving of the drillhole can produce a similar 'kick', hence low gamma and density associated with caliper expansions should be treated with caution when interpreting geophysical data. The amount of carbonaceous material required to produce an identifiable response can vary. The BPB coal interpretation manual (1981) states that, if configured optimally, horizons of ½ inch will produce a notable response. However examination of drill logs from the Greymouth Coalfield, where both descriptive and geophysical logs exist, indicates that in practical terms a coal or highly carbonaceous mudstone needs to be approximately 0.2m thick before consistent detection occurs. Hence boundaries placed using geophysical logs may not represent the first occurrence of any carbonaceous material but are instead the first sustained occurrence.

The geophysical method described above has proven to be an effective method for locating the Dunollie – Goldlight boundary. The distinctive saw toothed motif associated with the Goldlight Transitional Member is easily identified on most of the geophysical logs. Identification of the transitional motif quickly narrows the location of the Dunollie – Goldlight boundary to within ten meters. It is then normally a relatively simple matter to refine the boundary location by looking for the first occurrence of carbonaceous material.

In the south and east of the field area there are drillholes in which no Goldlight Transitional Member occurs. Determination of the Dunollie – Goldlight boundary from geophysical data is very simple for these locations. The boundary is marked by a change from the relatively smooth bulk density trace of the Goldlight Mudstone Member, to the fluctuating trace associated with the Dunollie Formation.

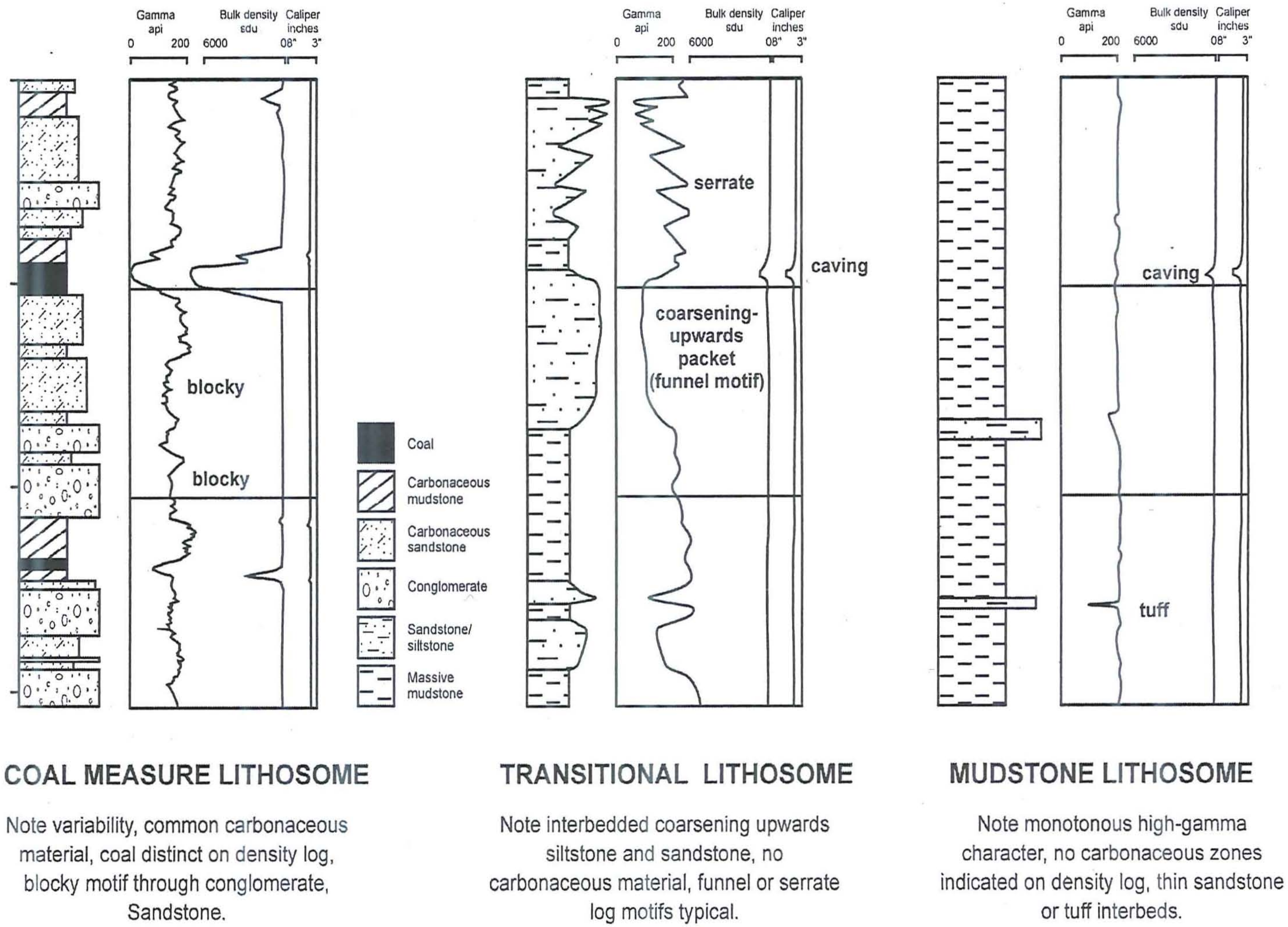


Figure 2.3: Lithologic and geophysical character of the three lithosomes identified within the Paparoa Group. Each section shows 30m. Copied with permission from Ward (1997).

2.3.2 Brunner – Dunollie Contact

2.3.2.1 Previous Work

Boundary definitions for the Dunollie Formation have in the past been based upon Gage's 1952 type sections. Although Morgan (1911) recognised the existence of the Paparoa beds, boundary relations both internally between Paparoa members, and between Paparoa sediments and other units were not subjected to detailed investigation. The type section for the Dunollie was defined as an outcrop exposure near the old Dunollie railway station (Gage 1952 pp. 37). The Brunner type section was also taken from this exposure as Gage felt he was unable to locate a satisfactory exposure of Brunner elsewhere.

Gage (1952 p.37) described the uppermost Dunollie conglomerate as 'comprised of greywacke, granite, and minor quartz' while the lower portion of the Brunner in the same area was described as 'consisting of a quartz conglomerate containing some greywacke'. Gage added that the Dunollie and the Brunner could be divided based on colour, the Dunollie conglomerate being light brown to grey, contrasted with the lighter coloured quartz dominated Brunner conglomerate. Gage also described a Brunner conglomerate that occurred only in the northwest of the Greymouth Coalfield. This conglomerate contained leached greywacke with minor pebbles of quartz and coal fragments.

This work on the Paparoa-Brunner boundary was extended by Wellman (1950) who examined sections in the coastal cliffs between Seven Mile and Ten Mile streams. Wellman reported a deep leaching of the undermass beneath quartzose coal measures (Brunner). This deep leaching Wellman ascribed to a significant break in regional deposition, whereby either erosion exposed in situ greywacke or cut a surface into the already deposited greywacke conglomerate. Deep-seated weathering then followed this exposure, and the greywacke basement and conglomerates were highly leached as a result. Wellman went on to suggest that sub-aerial erosion of this deeply weathered 'peneplain' formed the unconformity between the Brunner and the Paparoa Beds. Wellman (1950) proposed that Brunner Formation be restricted to the predominantly quartzose conglomerates, sands and associated coal. This placed Gage's northwestern "Brunner" conglomerate of weathered greywacke below the depositional break, making it Dunollie rather than Brunner Formation.

Wellman's broad division of the boundary between the Brunner Formation and Paparoa Group was examined as part of Nathan's (1978) work to update the Greymouth region's geological map. Nathan concluded that while the leached Brunner – Dunollie boundary reported by Wellman occurs in coastal exposures, such a division is lacking elsewhere in the Greymouth Coalfield, i.e. Sewell Peak, and also at Pike River coalfield. On the subject of the boundary in these areas Nathan (1978 p.13) noted that "although the base of the Brunner Coal Measures is marked by an increase in the proportion of quartzose sediments, there is no sign here of any weathering of the underlying beds nor of an erosional break". Nathan concluded that while sedimentation did come to a halt during the early Tertiary across most of the West Coast, it continued locally along the axis of the Paparoa Geosyncline, resulting in an apparently continuous succession between the Paparoa Group and the Brunner Formation. Within this area, Nathan defined the boundary between the Dunollie and the Brunner Formations as occurring with the gradational change from Dunollie conglomerate of greywacke and minor quartz clasts to Brunner Formation conglomerate of dominantly quartz with minor greywacke clasts.

As becomes apparent in the field, this definition makes the location of an exact boundary between the Brunner Formation and Dunollie Formation in the central portion of the Greymouth Coalfield more a matter of subjectivity and interpretation, than an objective division.

Attempts have been made to divide the Dunollie Formation from the Brunner Formation on the basis of palynological zonation. Samples taken from the Greymouth Coalfield were analysed and ordered in terms of the New Zealand terrestrial palynology zones (Raine 1984). Analyses by J. I. Raine of the NZ Geological Survey determined that Brunner Formation sampled from Spring Creek Rd is of palynological zone PM3 (also referred to as zone B). However, Raine placed the lower boundary of zone PM3 in the lower Goldlight Formation (Raine 1984). Raine also observed that the Brunner seam in Birchfields's Open Cast contained almost the entire MH1 zone (zone C) representing 7-8 myr (Newman 1985). Hence, at least in the centre of the basin, the Brunner Formation spans both the PM3 and MH1 zones and shares the PM3 zone with both the Dunollie and Goldlight Formations. Separation of the Dunollie and Brunner Formations is therefore not currently possible with the existing palynological zones.

2.3.2.2 Proposed Changes to Brunner Stratigraphy

Examination of the members that make up the Brunner Formation, and attempting to define a boundary between the Brunner and Dunollie Formations that is consistent with the boundaries for the rest of the Paparoa Group, has resulted in the proposal of a new stratigraphic system for the Brunner Formation. The proposed new nomenclature for the Brunner is shown in figure 2.4.

Group	Formation	Members
Rapahoe	Brunner	
Paparoa	Palaeocene Brunner	Brunner P
		Brunner Conglomerate
	Dunollie	

Figure 2.4: Proposed Stratigraphy for the upper Paparoa Group and Brunner Formation.

The Brunner Formation is the largest unit in the proposed stratigraphic system. The Brunner Formation encompasses all of the Eocene Brunner material previously documented by Gage (1952) and Nathan (1978), and extends beyond the boundaries of the Greymouth Coalfield.

The Palaeocene Brunner Formation is so far only reported within Greymouth Coalfield. The Brunner P. Member (after Nathan et al 1986) encompasses Brunner material identified by Newman (1985 pp 26) and Raine (1981) to be Palaeocene to basal Eocene on the basis of pollen assemblages. Newman (1997) has since conducted further palynological dating of the Brunner Coal Measures from Greymouth Coalfield. She observed that Middle Eocene age Brunner Coal Measures are absent over much of the coalfield and suggested that the Island Sandstone therefore often rests on Brunner P.

The boundary between the Dunollie Formation and the overlying Brunner Formation requires definition of a new unit. As defined in this thesis the Dunollie now terminates at the final occurrence of carbonaceous material below the conglomerate sequence previously attributed to the Dunollie by Gage (1952) and Nathan (1978). This change is in order to bring the Dunollie – Brunner contact inline with the boundary criteria used within the Paparoa Group (after Ward 1997). The Brunner Formation therefore begins with the conglomerates (Chapter 2.3.2.1). The conglomerates themselves are now defined as a sub-unit of the Palaeocene Brunner Formation to be known as the Brunner Conglomerate Member. The Brunner Conglomerate Member is new, defined for the first time in this thesis. It contains basal Brunner conglomerates, extending from the top of the upper-most conglomerate downwards until the first carbonaceous horizon is reached, signalling the top of the Dunollie Formation.

Problems exist with defining the Brunner conglomerates as a single member. The conglomerates are laterally discontinuous and are interbedded with sandstones raising the question of which formation the sandstones belong to, Dunollie or Brunner P. Detailed mapping of the sandstones would be required to determine whether they grade into one or other of the bounding formations and hence should be included within that formation. Alternatively the sandstones form lenses of material within the conglomerates and hence can be considered a sub-unit of the Brunner Conglomerate

Member. The occurrence of these sandstones above the newly assigned Dunollie boundary and their lack of significant carbonaceous material (Gage 1952) excludes them from inclusion with the Dunollie Formation. Inclusion of these sandstones into the Brunner P would be questionable, given the current lack of field exposures where these sandstones can be seen in relation to the overlying Brunner P. Hence, these sandstones are classified here as part of the Brunner Conglomerate Member.

The discontinuous nature of the uppermost Dunollie – Brunner coastal conglomerates, with highly leached material overlain by relatively fresh conglomerate (Gage 1952; Wellman 1950) also presents a problem. Newman (1985) identified a burrowed and highly silicified horizon within the Brunner Formation at Sewell Peak. Palynological dating resulted in the silicified horizon being interpreted as representing an unconformity of 10 m.y. within the Brunner sequence. Raine's (1984) palynological dating of the Brunner Formation at Birchfields Opencast identified a similar hiatus at the top of the main coal seam. It is therefore proposed that cessation of Palaeocene accumulation may have been diachronous. That is, net deposition may have ceased earlier near the basin margins than at the basin axis. Eventually however, accumulation ceased across the whole basin for approximately 10Ma. Further work is required to date the depositional break in the coastal succession and if possible to trace the stratigraphic location of the hiatus across the basin. Figure 2.5 provides a schematic cross-section showing the postulated stratigraphic relationships and occurrence of the unconformity.

The unconformity shown within figure 2.5 separates two tectonically distinct units; (a) local rift related Palaeocene Brunner, and (b) regional transgression related Brunner Formation (pers comm Larid 2000).

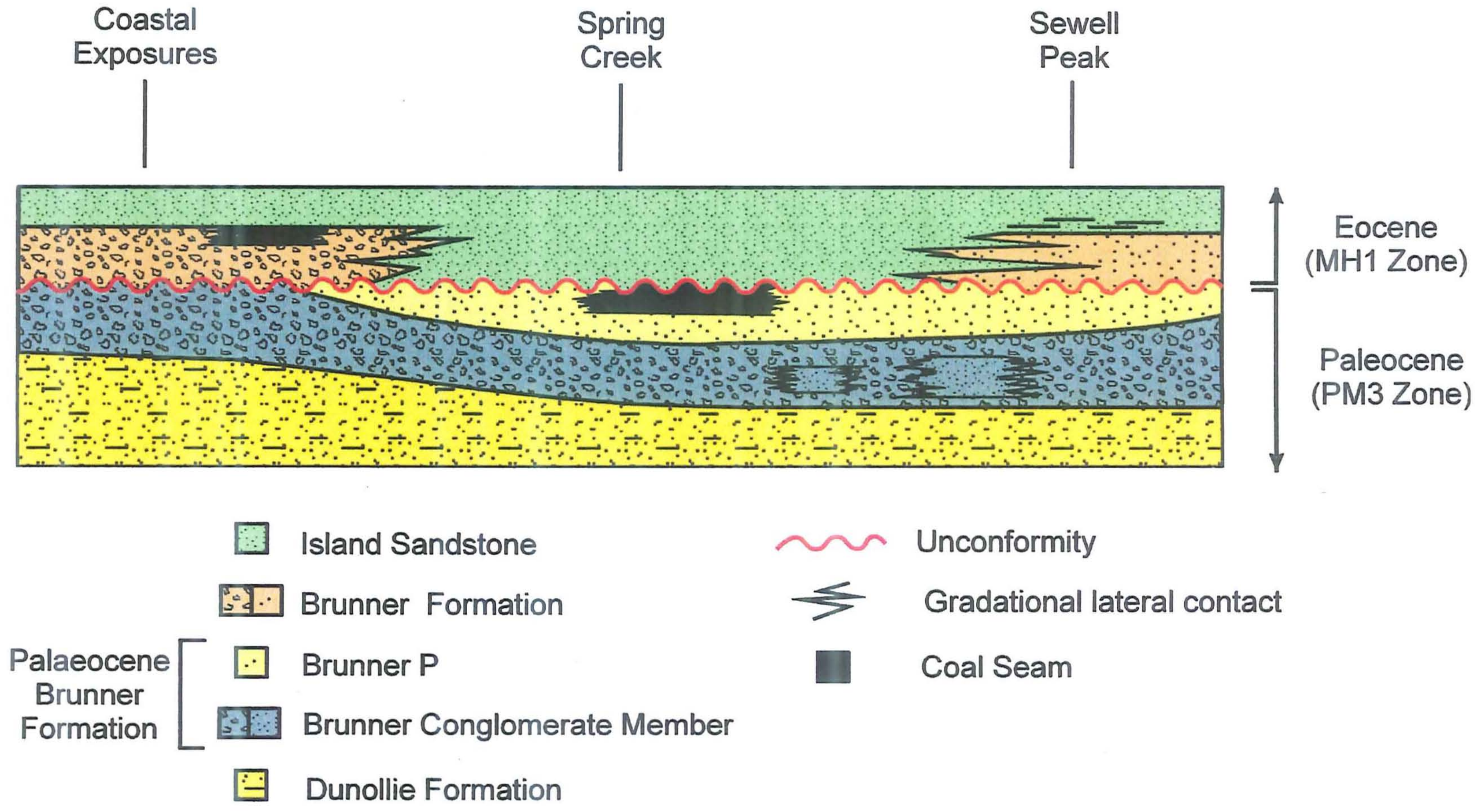


Figure 2.5 Lithostratigraphic summary diagram,
Brunner and bounding Formations, Greymouth Coalfield.
Theoretical cross-section showing proposed relationships between Formations and Members.
(Not drawn to scale)

Lever (1999) suggests that the Eocene Brunner be placed into the Rapahoe Group because it represents the basal unit of the widespread Tertiary marine transgression. She proposes that the new Rapahoe Group should consist of all marine and marginal marine sediments associated with the regional marine transgression. This comprises all the sediments deposited between the basement or fluvial Paparoa Coal Measures, and the first occurrence of widespread limestone representing maximum transgression. Past authors have argued that this grouping does not allow for the extensive distribution of the Brunner when compared to other Tertiary units (Nathan 1974, Gage 1952). But Lever (1999) refutes this assertion, arguing that this objection is reliant on the stratigraphic naming conventions for the region. Past stratigraphic systems have restricted the 'named' occurrence of Tertiary formations (other than the Brunner) to outcrops, which share a visible physical link. This results in the argument that the Brunner is more widely distributed than the other sediments of the proposed Rapahoe Group, because it is consistently labelled as Brunner throughout the region while the other Tertiary formations are not.

I suggest that the Palaeocene Brunner Formation be included within the Paparoa Group. Inclusion of the Brunner P and Brunner Conglomerate Member within the Paparoa Group is due to the limited distribution of these members, they are restricted to the Paparoa Trough, and they are not associated with the Eocene marine transgression.

It is suggested that a future investigation map the extent of both Brunner P and Brunner Conglomerate Members. Such an investigation should give consideration to renaming the Palaeocene Brunner Formation, in order to distinguish it from the regional Brunner Formation. The newly named formation should still be part of the Paparoa Group.

2.4 Summary of Proposed Changes

The investigation and changes proposed to the Greymouth Coalfield stratigraphy sought to examine the application of Wards (1997) boundary system for the Paparoa Group, and to extend the updated boundary criteria to include the upper Dunollie and Brunner Formations at Greymouth, which was beyond the scope of Ward.

Examination of the Goldlight – Dunollie boundary indicated that the definition of the Dunollie Formation as lying above transitional lithosomes was valid within the study area. Placement of the lower Dunollie boundary at the first sustained occurrence of carbonaceous material provided a robust system for determining the boundary position. One of the primary goals of Ward's (1997) system was the placement of formation and member boundaries accurately from geophysical data. As detailed above (p.32) determination of the Goldlight – Dunollie boundary from geophysical logs proved straight forward using the refined boundary criteria.

Extending consistent boundary criteria to the Dunollie – Brunner boundary resulted in the proposal of a new stratigraphic system for Brunner material at Greymouth. The existing Brunner Formation of (Nathan 1974 and Gage 1952) was divided into two formations, based on age and distribution. The resulting formations are the Brunner Formation and the Palaeocene Brunner Formation. The Brunner Formation encompasses all of the Eocene material, and extends beyond the Greymouth Coalfield. The Palaeocene Brunner Formation is made up of the Brunner P Member and the Brunner Conglomerate Member. These members contain all of the Palaeocene to basal Eocene Brunner material as well as the entire conglomerate sequence above the Dunollie Formation.

The boundary between the Dunollie – Palaeocene Brunner Formations is defined as occurring at the top of the first carbonaceous sediments below the conglomerates.

Chapter 3

Deposition, Sedimentary Controls

3.1 Introduction

This chapter details the occurrence and composition of the revised Dunollie Formation and Goldlight Transitional Member. Distributions, thickness, sedimentary structures, and coal occurrence are described and discussed.

The approach taken in this chapter is not that of a traditional sedimentological investigation. Instead it is aimed at producing a model of deposition and mire formation. The field investigation therefore focussed on detailing the relationship between basin wide sedimentary trends and coal occurrence. Distributions and unit thickness are presented based on the adjusted formation boundaries and divisions presented in Chapter 2. Data from drillhole logs has been refined, in order to show both specific depositional environments and the change in depositional environment across the study area. This detail and discussion provides part of the evidence to support the paleoenvironmental interpretation in Chapter 5.

It was not an objective of this investigation to produce a detailed account of the sedimentology of formations in the upper Paparoa Group. For such a review the reader is directed to Gage (1952), Wellman (1950), Nathan (1978), and Nathan et al (1986).

3.2 Field Work

3.2.1 Introduction

The primary goals of the surface investigation were to (a) locate and sample coal exposures from the Dunollie and Brunner Formations within the study area and (b) develop an understanding of formation stratigraphy within the field area and the nature and distribution of coal occurrence within these formations.

3.2.2 Field Observations

The study area can broadly be described as a major north-north-east trending ridge joined at the northern end into a small plateau, incorporating several smaller ridges from the area surrounding Trig K No. 3. Figure 3.1 provides a topographic map of the study area, including major streams, the abandoned New Point Elizabeth Mine workings and the locations where samples where collected.

Elevation across the field area varies from ~70m in the base of Seven Mile Creek up to ~410m at Trig K No. 3 in the north. The western and southern portions of the field area are covered in dense regenerated native beech forest growing on weathered Goldlight Formation. In the northern and central portions of the area, the nutrient-poor soil, resulting from weathering of the quartz rich Brunner and Dunollie Formations, supports the growth of only minimal sub-alpine plant life. Such terrain is difficult at best to work in; the forested sections have a severely limited visibility while the scrub-covered portion of the field area limits movement and visibility of the actual ground surface. Horizontally traceable outcrop is limited mainly to bluff or cliff face exposures while vertically continuous exposure is limited to stream cuttings and runoff guts. Due to the nature of the terrain and the small size of the coal seams (generally 20 – 30 cm thick) most coal occurrences are only detectable by passing physically over the top of them. However the base of cliffs and bluffs provide a good place to begin searching as the coal seams appear to have acted as failure surfaces within the outcrops. Hence many of the cliff faces, both major and minor within the area have coal occurrences at their base. In the northern central portion of the field area this effect provides a noticeable change in slope at the transition from Dunollie Formation to the Brunner Conglomerate Member (figure 3.2).

Significant coal exposure within the Dunollie Formation is limited to the southeastern portion of the field area, north of Seven Mile Creek (figure 3.1). Thick coal occurs in the vicinity of drillhole 638 and formerly over the area exploited by the New Point Elizabeth Mine. Within this area there remains only one good exposure of the major upper Dunollie seam where seam thickness exceeds 3m (CN1 0.7 – CN1 3.10). This exposure is the only one of its kind seen during the course of fieldwork.

North and west of the New Point Elizabeth Mine the occurrence of Dunollie Formation coal rapidly decreases. At the “Water Fall” outcrop (pictured in figure 3.3) beneath Birchfields Opencast (Brunner P) workings, carbonaceous horizons are limited in both occurrence and thickness. In this northern part of the field area there are two main horizons composed of multiple thin coal seams. Three thin seams occur in a 2m coal horizon at the top of the Dunollie sequence, forming the “Water Fall” outcrop (samples CN6/1, CN6/2 and CN6/3). The remaining two seams are located in the bottom third of the Dunollie sequence, these are limited in thickness to approximately 20 – 35 cm of coal interbedded with fine sandstones and carbonaceous mudstones. Occasionally very thin (1-2 cm) zones of coaly sediment lie above or below the thin lower seams.

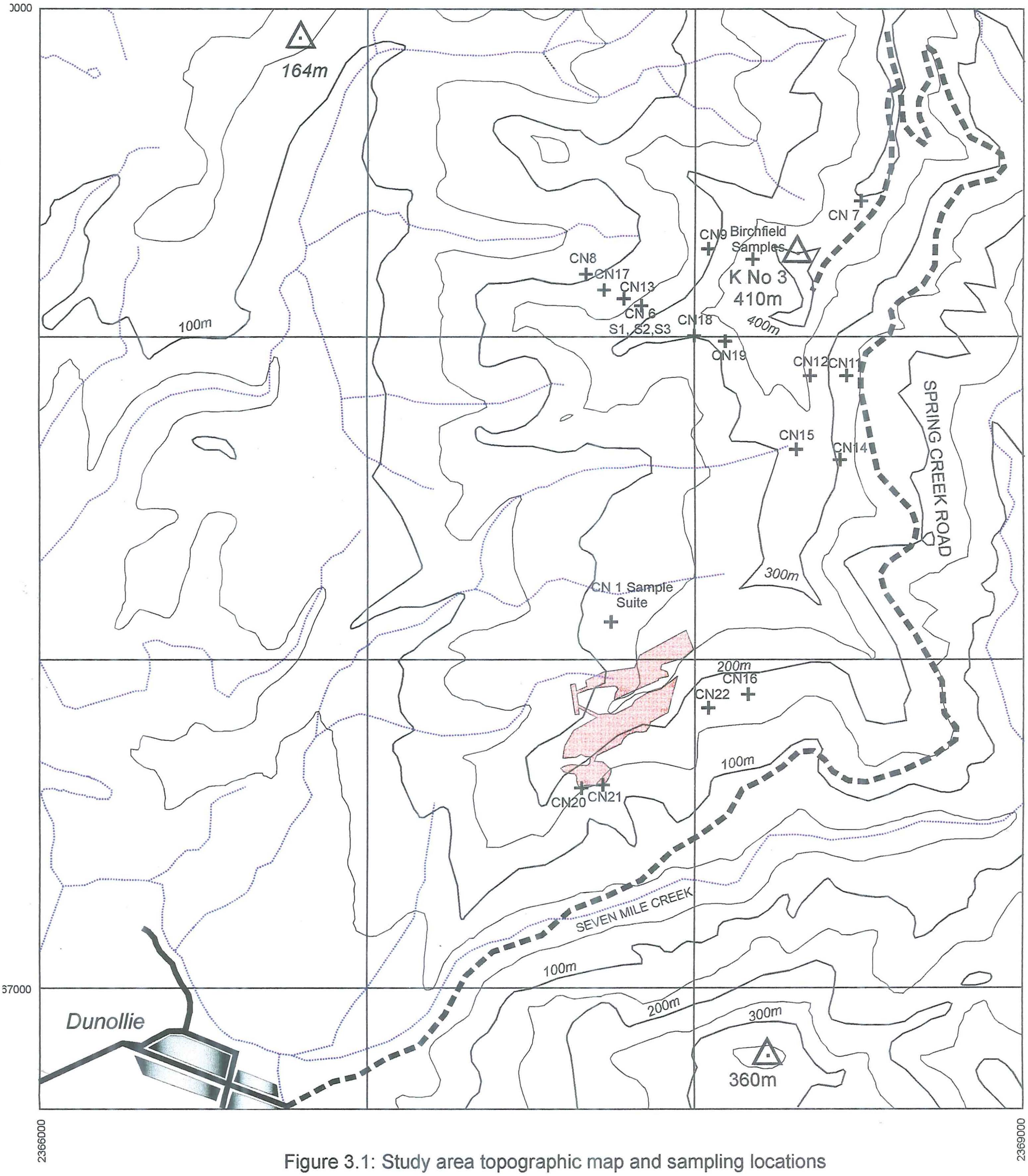


Figure 3.1: Study area topographic map and sampling locations

Based on NZMS 260 J31 Greymouth and New Point Elizabeth Mine Records

Sealed Road
Unsealed Road
Streams
Residential Area
Contours
50 m Contour divisions
New Point Elizabeth Mine Workings (Abandoned)

0 0.2 0.4 0.6 0.8 1.0 2.0

Kilometers

Figure 3.2: Dunollie Brunner Contact,
Red Line marks the approximate location of upper most
Dunollie Seam.

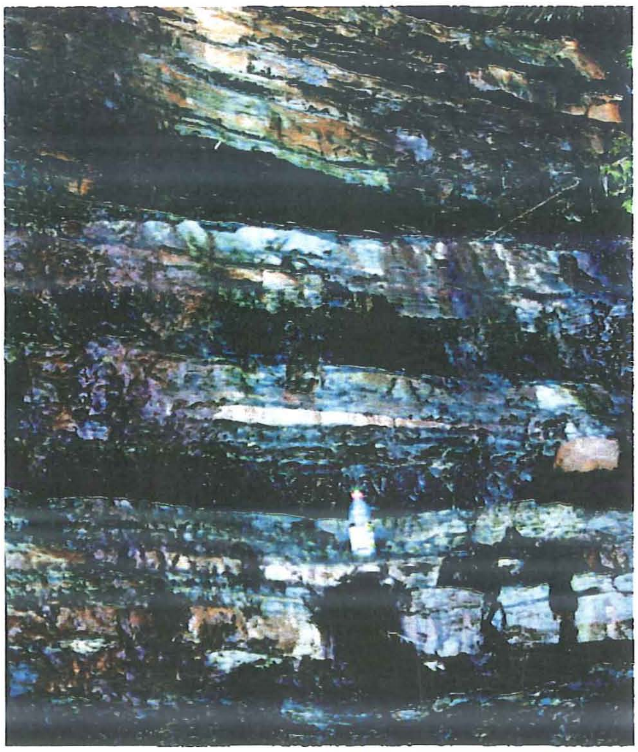


Figure 3.3: 'Waterfall' outcrop
(bottle is ~25 cm tall)

Two hundred meters further north seams contemporaneous with the "Water Fall" horizon are exposed again at the base of a cliff (sample CN9, figure 3.1). At this location the seams are further attenuated and are beginning to lens into and out of carbonaceous sandstone. The same trends apply on the eastern side of the ridge, where a thinned upper seam (~20 – 30cm thick) occurs at the base of cliffs just below the 300m contour (sample CN11).

In the extreme northeast of the field area (north and east of sample CN7) only thin laterally discontinuous carbonaceous material occurs within interbedded sandstones. Road cuttings for Spring Creek Rd, especially the series of hairpin bends that mark the northernmost extent of the road, provide the best view of Dunollie Formation sediments in the north of the field area (figure 3.1). Carbonaceous material in these exposures is limited to thin plant beds and scattered leaf remains; fossilized roots are common. The upper boundary of the Dunollie Formation is marked by a thin discontinuous seam ~5cm thick. Investigation of stream cuttings and runoff guts in the area support observations from the road cuttings, confirming that only very thin and discontinuous carbonaceous horizons occur in this area.

Coal occurrence south of the 3m coal exposure near DH638 (sample CN1) is relatively difficult to locate due to extremely heavy bush cover and concealed bluffs. However, available observations indicate that the Dunollie seams thin rapidly to the south of the New Point Elizabeth Mine. The two portals in the northwest of New Point Elizabeth Mine workings have collapsed to the point where investigation and sampling was impossible. However, open access portals were located into the southern portion of the mine, and two separate block samples were retrieved for later analysis (samples CN20 & CN21). A single seam with a thickness of approximately

25~30cm occurs at the portal openings. This seam is interpreted as the uppermost Dunollie seam, and appeared to extend continuously between mine portals, and into the workings. The seam appears to thicken into the mine workings, and mine records held by the national archives record 1-3 meters seam thickness (New Point Elizabeth Mine 1930 and 1946). The extremely hazardous nature of these abandoned mine workings limited access and exact measurements were not gathered in order to minimise the time within the workings. Seam thickness was from visual estimation only, and no information was retrieved from deeper than 7m from the portal mouths, at which point roof conditions made further work impossible without specialised equipment.

South of the New Point Elizabeth Mine the Dunollie Formation has been eroded by Seven Mile Creek and for a distance of approximately six hundred meters no information about coal seam occurrence is possible (figure 3.1). Exposure on the southern side of Seven Mile Creek is currently inaccessible due to extreme colonisation of the lower slopes over the last decade by gorse. However, K. Brown (1994) provides a relatively recent log of the outcrop, in which only thin occurrences of carbonaceous material are recorded. Hence it is concluded that the upper Dunollie seam thins or terminates in this direction.

Based on field observations it is concluded that the occurrence of significant coal seams is restricted to the upper Dunollie in an area of approximately two square km located within the southwestern portion of the field area. The New Point Elizabeth Mine extracted the thickest portion of the main upper Dunollie seam.

A laterally restricted pod of thick coal occurs in the lower Dunollie, south of Seven Mile Creek upstream from the field area. This seam, once extracted by the Tiller Mine, was outside of the scope of this thesis.

3.2.3 Samples

Samples were collected from all coal seam occurrences located within the field area. Orientated block samples were collected from all seams for later mounting as petrographic blocks. Some seams were channel sampled and divided into plys. Material from channel samples was sent away for chemical analysis.

A full description of sample type and location are provided in Appendix 1. Coal properties are the subject of Chapter 4.

3.3 Drillhole Investigation: Methodology and Rationale

Determination of Formation and Member occurrence, thickness and relative position is difficult from field exposure. This is due to a combination of relatively discontinuous or isolated outcrop, poor vertical continuity, and very limited outcrop of the lower Dunollie Formation. These limitations led to a method of investigation based mainly on drillhole information. The fieldwork investigation focussed on locating and sampling coal seams within the study area, hence aided in the determination of trends in coal occurrence. Examination of outcrop also provided the basis for interpreting the fluvial systems responsible for deposition of the Dunollie and Goldlight Formations.

Drillhole information, specifically geophysical data, is the most reliable and consistent source of information for the units in Greymouth Coalfield. The Coal Resource Survey (CRS) and Greymouth Coal Ltd. (GCL) drilling programs focused on core extraction from the more prospective Rewanui Formation, hence for many drillholes geophysical data is the only information available for the Dunollie and Goldlight Formations.

Although CRS drillholes were often cored through both the Dunollie and Goldlight Formations, much core was discarded due to subsequent storage limitations. Generally both geophysical and graphical logs exist for the CRS drillholes. The graphical logs are particularly useful as in most cases they have been created directly from core inspection at the time of drilling. However, problems do exist with the graphical logs. The formation boundaries are based on Nathan's (1978) system (as detailed in Chapter 2). Also, some of the first logs produced use combined sheets for the graphical and descriptive information, which causes problems as the amount of lithologic detail relates directly to the space used to describe a unit. For example the Dunollie and Goldlight descriptions (approximately 250m of core) are in some cases compressed into the top 5cm of the log, while the Rewanui (~300m of core) occupies most of the remaining log (140+cm).

The GCL exploration program was designed specifically to define a coal resource within the Rewanui Formation. Due to the high cost of coring, only basal Goldlight and Rewanui Formation were cored. Units higher in the drillholes were drilled using an open-hole method. Fortunately however, geophysical logging was completed for the entire length of all GCL drillholes.

The drillhole data set from both CRS and GCL were reviewed. Important criteria for selection of drillholes used in this study were the units intersected, whether they were cored or open holed, and water level in the drillhole. Holes that did not intersect the Dunollie Formation were discarded immediately. Those holes that contained Dunollie material but did not include contact with the overlying Brunner Conglomerate Member were retained for use in areas where information was required and no full logs existed. Water level controls the depth below which geophysical methods can be used. A fluid filled hole is required for a consistent geophysical response. A small number of CRS drillholes had very low water levels, possibly due to faulting or shearing. Where no high quality descriptive log existed for one of these 'dry' holes the hole was excluded from this study.

Figure 3.4 shows the locations of drillholes investigated as part of this project. Virtually all drillhole numbers refer to holes drilled as part of either CRS or GCL investigations. However, drillhole 433 was drilled much earlier.

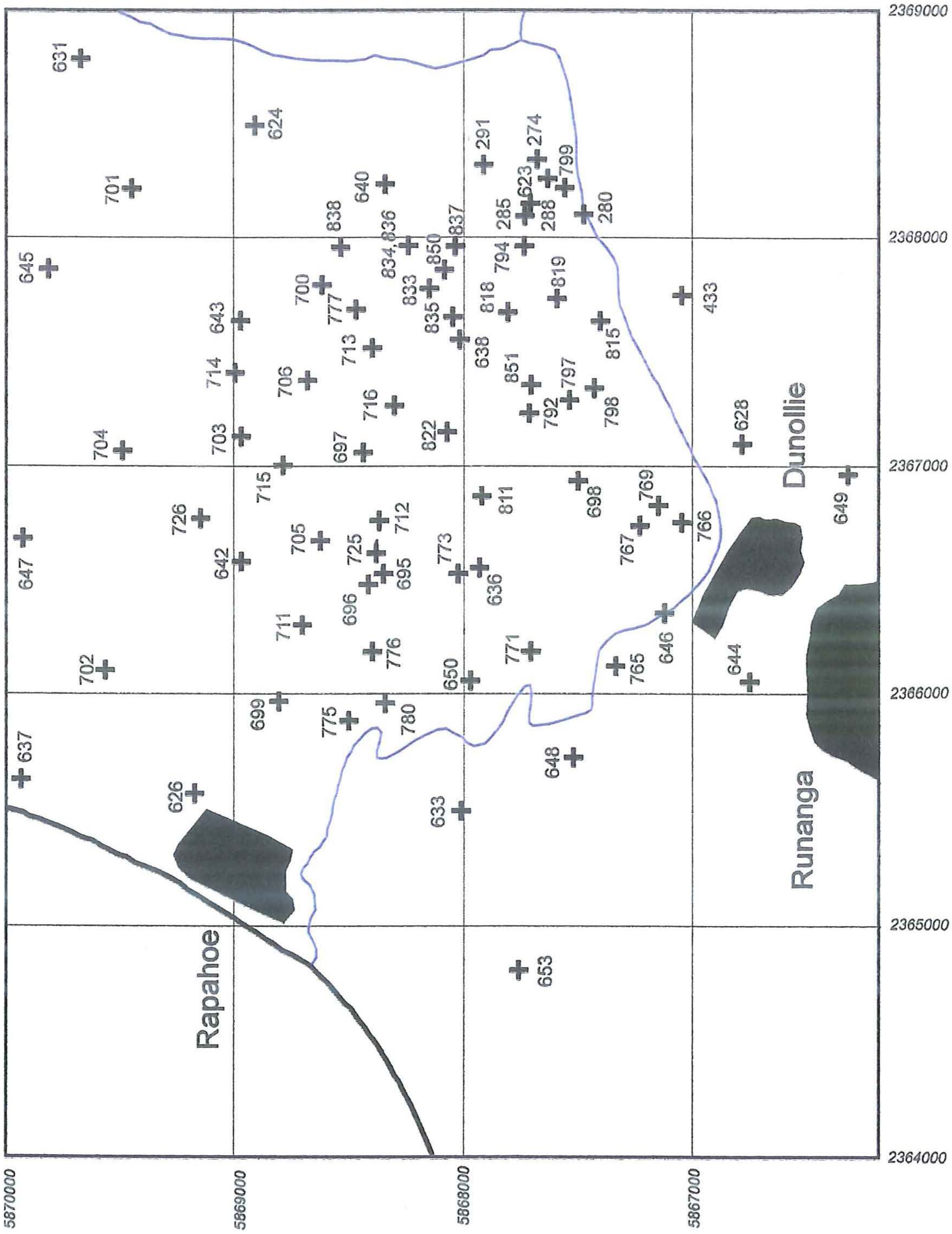


Figure 3.4: Location of selected Greymouth drillholes

(After Ward 1997, GCL drillhole location maps and NZMS 260 J31 Greymouth)

Graphical logs were examined for the selected drillholes. For those drillholes where no graphical log existed one was created from the geophysical log with reference to the nearest drillhole for which a graphical log existed. Comparison between the graphical logs generated purely from geophysical logs, and graphical logs generated from a combination of core and geophysical log, was done to increase the accuracy of the interpretation.

The second stage of refinement for the drillhole logs was application of the revised unit boundaries from Chapter 2. Both graphical and geophysical logs were examined and the location of Dunollie Formation boundaries was reviewed. The Goldlight Transitional Member was marked in on drillholes where it occurred, and the overlying Brunner Conglomerate Member was also distinguished.

3.4 Processing of Drillhole Information

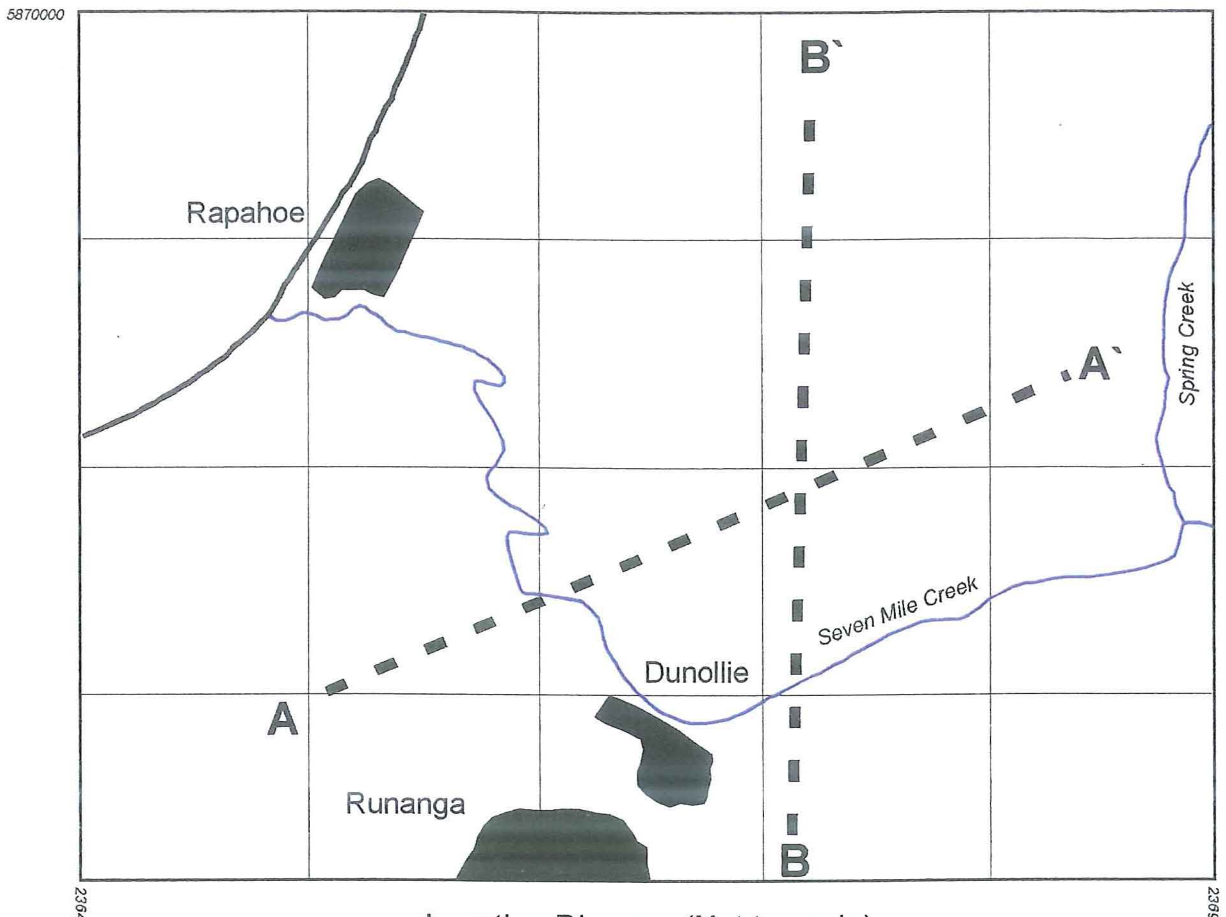
3.4.1 Introduction

Examination of the drillhole data set had two main goals. To study the vertical relationship between formations and determining the distribution of various units within the basin. To these ends both cross-sections and isopachs were produced. Two types of cross-sections were produced. Sheets 1-4 represent gross lithology and the occurrence of coal seams within the Dunollie and bounding formations, and a second pair of cross-sections with five times vertical (figure 3.5), show how the formations relate to each other and to the basement.

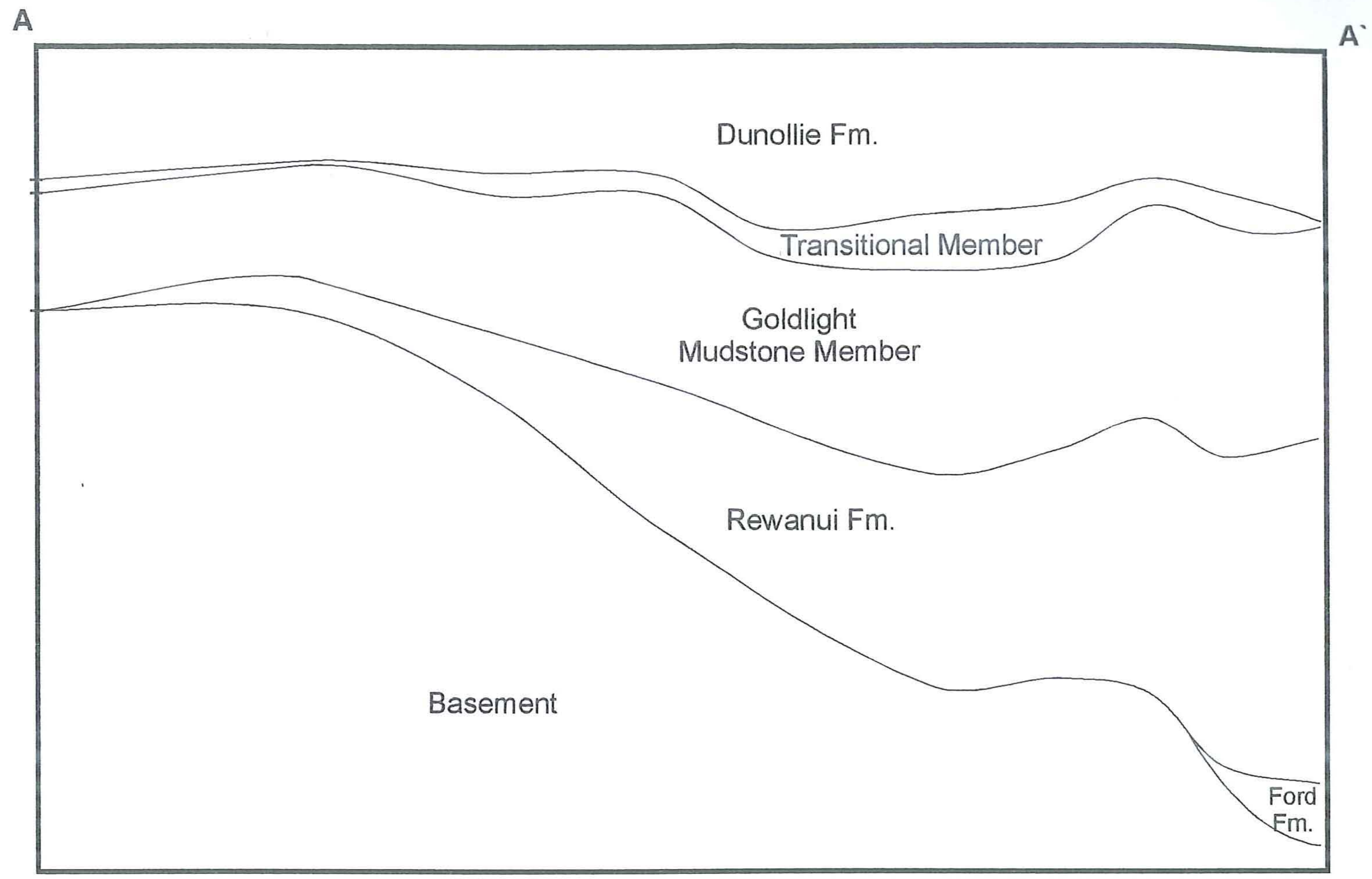
3.4.2 Cross-sections

A series of optimal drillholes was identified for the construction of cross sections from the refined drillhole data set. Cross sections were produced using the base of the Brunner Conglomerate Member as the reference datum (Sheets 1-4). DH638 was chosen as a tie point for the section lines on the basis of the quality of the drillhole data, the good spread of drillholes surrounding DH638 and the occurrence of outcrop in the area. The availability of outcrop also allowed field sampling of seams identified in the drillhole. Because of the limitations of graphical logs produced from geophysical data the cross-sections were kept relatively simple. Gross lithology was plotted along with formation boundaries and carbonaceous mudstones / coal seams.

Two scale cross-sections were generated from the isopachs (figure 3.5). These sections show the relative thicknesses of formations in the upper Paparoa Group and the relationships which units have between one another and with the basement.



Location Diagram (Not to scale)



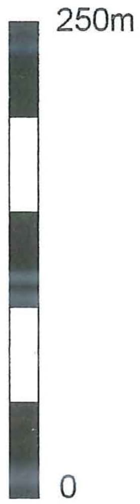
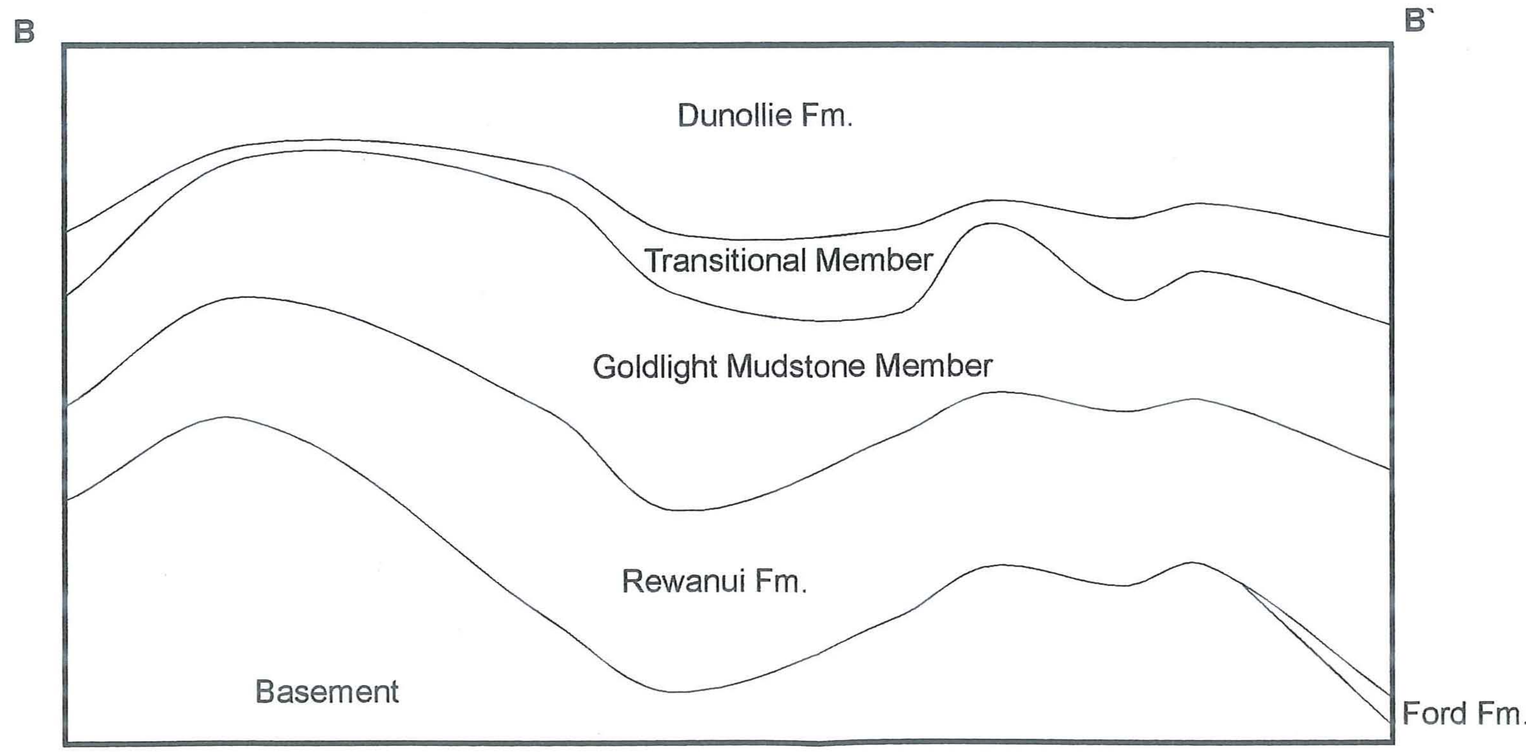


Figure 3.5: Cross-sections through the southwestern Paparoa Basin
Horizontal scale 1:20000, vertical exaggeration = 5:1.

Unit thickness derived from drillhole and isopach data
Rewanui and Ford Formations after Ward 1997.



3.4.3 Isopachs

Gage (1952) produced isopachs of the Dunollie and other formations within the Paparoa Group. His work was based on the limited drilling available at the time and on unit thickness in outcrop. Application of new formation boundaries to the Dunollie and inclusion of the Goldlight Transitional Member now allows for the development of new isopachs for these units, reflecting the newly defined distributions. The revised isopachs use the CRS and GCL drillhole data sets and are based on the new formation boundaries detailed in Chapter 2.

Dunollie Formation: Data points on initial drafts of the revised Dunollie isopach were reviewed. Points that appeared to be of an abnormal thickness or represented a strong divergence from surrounding points were reassessed and the thickness of several points was revised. Most revisions were related to the identification of faults based on the drillhole logs and the recognition of carbonaceous material missed during initial logging but recorded in geophysical logs. A final isopach of the revised Dunollie Formation was then produced (figure 3.6).

Goldlight Formation: Two isopach maps were produced from the component members of the Goldlight Formation. The first isopach is of the Goldlight Transitional Member (figure 3.7), while the second is of the Goldlight Mudstone Member (figure 3.8). The Transitional Member isopach corresponds to Ward's (1997) upper Transitional Member but there are differences in thickness and interpretation as the revised isopach includes data from holes drilled after Ward's investigation. The zone delineated by a jagged line in the northwestern corner of the Goldlight Transitional Member isopach is an area where the Goldlight Formation consists only of transitional lithosomes.

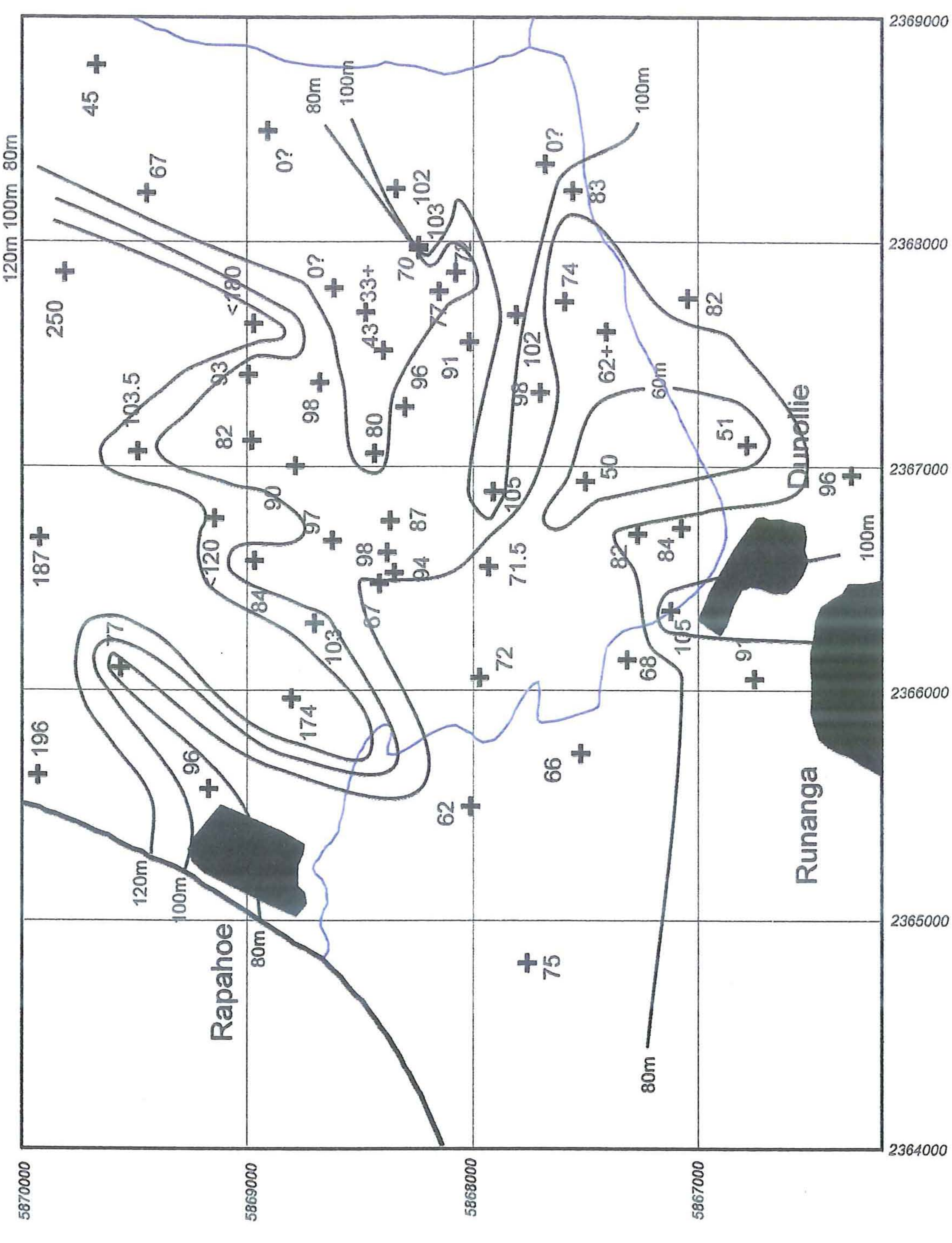


Figure 3.6: Isopach of the Dunollie Formation

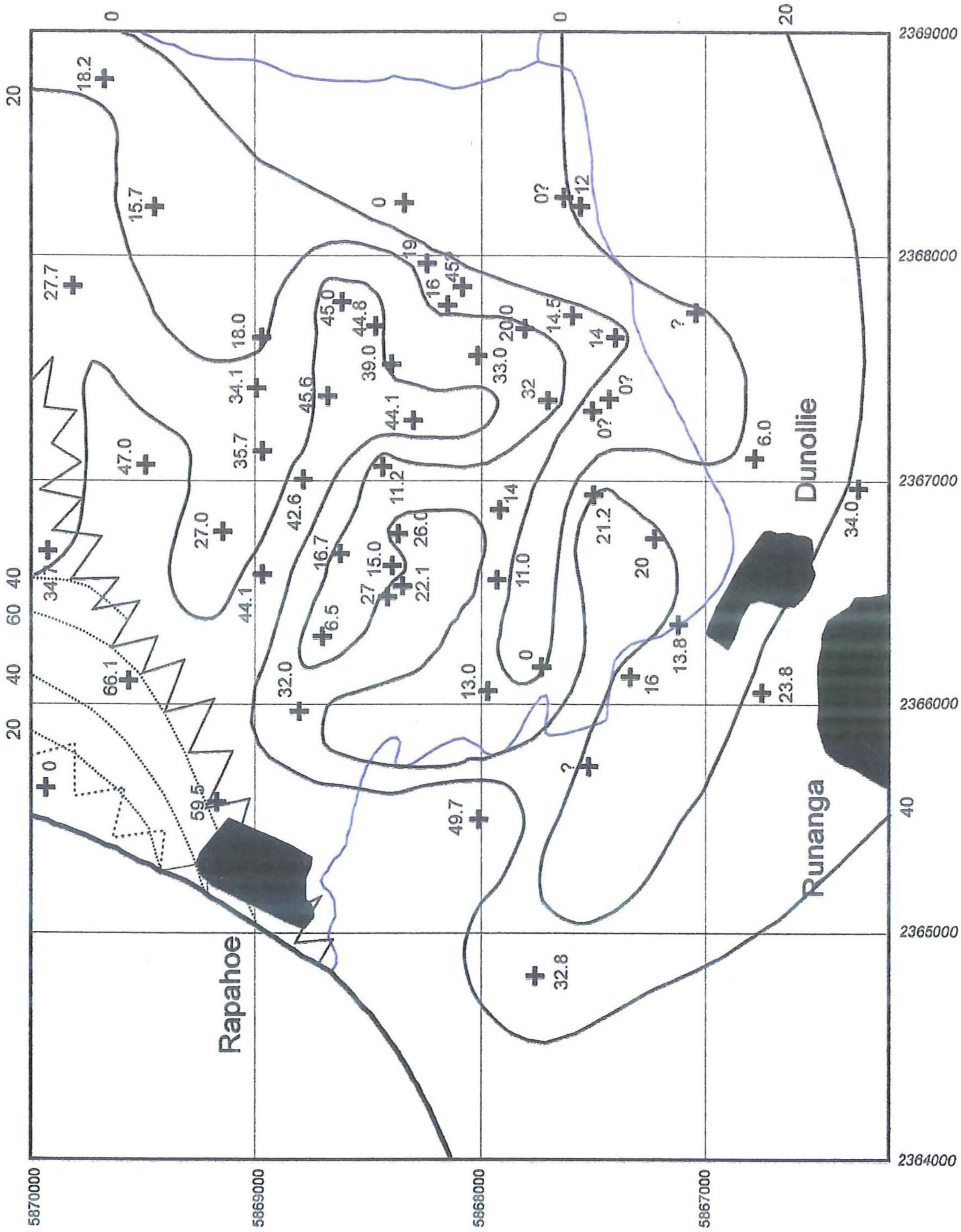


Figure 3.7: Isopach of Goldlight Transitional Member

The zone in the northwest corner is an area of Goldlight Formation that consists entirely of transitional lithosomes, i.e. there is no mudstone member.

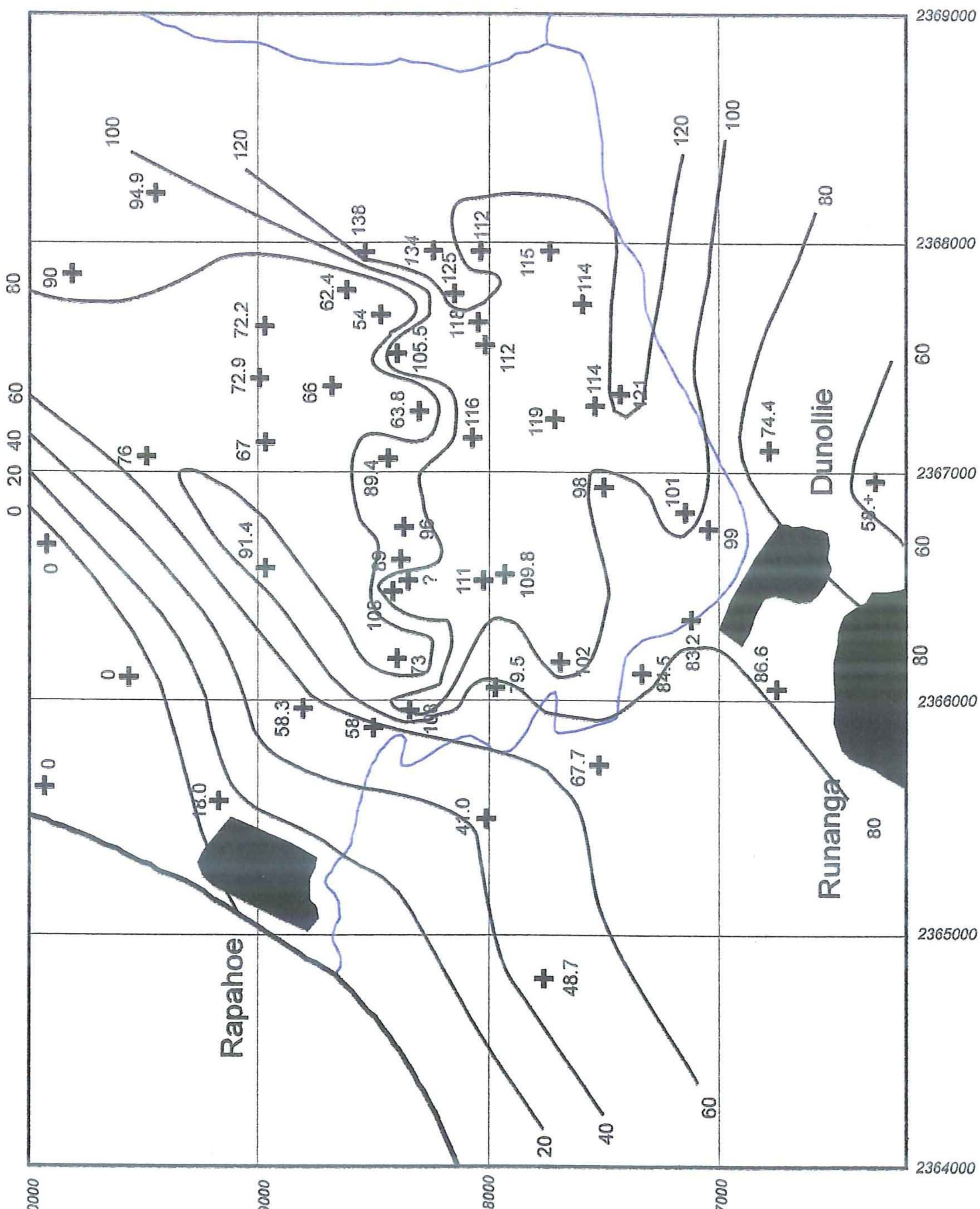


Figure 3.8: Isopach of the Goldlight Mudstone Member.

3.5 Discussion

3.5.1 Goldlight Mudstone Member

Goldlight Mudstone Member (MM) underlies all of the study area except for the northwestern corner (figure 3.8), and is the lowest unit in the stratigraphic sequence examined in detail during this study. The Goldlight MM has long been recognised as being the result of the development of a lake within the Paparoa Basin (Morgan 1911, Gage 1952). This lake occupied a broadly asymmetrical basin controlled by NNE–SSW oriented structures (Ward 1997). Onlap onto the flexural margin in the southwest allowed the Goldlight Lake to deposit a substantial thickness of mudstone where Rewanui Formation is very thin (figure 3.5). It is likely that mudstone was deposited directly on to exposed basement not far southwest of the limit of present drillhole coverage.

Ward (1997) proposed that the Goldlight MM accumulated during a period of basin expansion driven by regional orthogonal extension. The expansion of the basin resulted in reversal of the southern axial drainage pattern, with previously deposited sediments being reworked and moved northward.

Low energy conditions during Goldlight deposition resulted in a massive mudstone unit. Some sections show light and dark banding, possibly indicating seasonal fluctuations in the composition of supplied sediment. Fresh water mollusc fossils throughout the Goldlight MM sequence confirm fresh water lacustrine conditions within the lake. The stable conditions and restricted sediment types present within the Goldlight MM have resulted in a distinctive geophysical trace. Gamma is relatively smooth and consistent, generally around 200 API, while the density trace stays high and very smooth.

During deposition of the Goldlight MM a series of sediment point sources remained active to the northwest of the basin, resulting in sediment transport into the northwestern corner of the study area. Consequently a low angle plane of alluvial material bounded the Goldlight Lake to the northwest. This alluvial material formed a continuous sequence of carbonaceous sandstones resulting in the apparent transition directly from Rewanui Formation up into Dunollie Formation in the northwest. A thin transitional margin existed between this sub-aerial alluvial fan and the Goldlight Lake.

Sediments deposited within the western transitional margin ranged in general from mud to very fine or medium sand. Granules are the maximum size deposited. This indicates that activity in the northwestern source area, although sustained, was not intense during deposition of the Goldlight MM.

3.5.2 Goldlight Transitional Member

Deposition of the Goldlight Transitional Member occurred in Southern Rapahoe Sector, and the present study is focused north of Dunollie Township and west of Spring Creek. Although Transitional Member deposition also occurred south of Dunollie Township this occurrence is not dealt with in any detail here, because it is outside the study area and no additional information has been produced south of Dunollie since Ward's 1997 investigation (Ward 1997 Chapter 7). Distribution of the Goldlight Transitional Member within the study area is shown in figure 3.7.

This transitional margin formed as distributary mouth bars prograded into the lake. Channel abandonment was common due to sediment infilling, resulting in migration of channels and mouth bars (Weimer 1973, Orton 1988, Flint et al 1989). The Goldlight Transitional Member generally consists of a mixture of mudstone and fine to medium sandstone, occurring as coarsening upward packets of sediment. Thickness of the coarsening upwards packets ranges from 1 – 25m, and the Goldlight Transitional Member consists of approximately 3 – 15 packets at any given location. These packets produce a distinctive geophysical trace as detailed in chapter 2. (figure 2.3). Examination of core from drillholes where the Goldlight Transitional Member is well developed indicated that the Goldlight Transitional Member is also visually distinctive. In core the Goldlight Transitional Member appears as repeating packets of dark mudstone that grade upward into lighter coloured sandstone. Packet boundaries consist of a sharp unconformable contact between the light coloured sandstone and the overlying dark mudstone. These transitional lithosomes are interpreted here as the product of a prograding lobate or birdsfoot delta into the Goldlight Lake (Hyne et al 1979, Ayers 1986, Tye et al 1999 and Bruhn 1999). The lack of coarse sediment components and absence of steep foreset beds indicates that the delta was not a Gilbert type delta (Jackson et al 1979, Lemons & Chan 1999). Also the lack of steep foreset beds combined with the absence of turbidite sands within the Goldlight MM indicates that the Goldlight Lake was relatively shallow (Postma 1990). Water depth was unlikely to have exceeded the maximum sediment packet thickness of 25m (Tye & Coleman 1989, Farquharson 1982). These observations conform with those made by Ward (1997), who also proposed a deltaic method of formation for the transitional deposits.

Deposition of bar finger and mouth bar sands occurred at the delta front, while on the delta plain the relatively low angle and small sediment size combined to hinder the development of levees, which would have contained the distributary channel system. The lack of channel constraint and the infilling of channels by sands allowed the diversion or rapid migration of channels into interdistributary areas resulting in the sharp cut-off of coarse grained units and the rapid lateral changes in sand body frequency and thickness (Ward 1997; Kreisa et al 1998). The lack of well developed carbonaceous horizons or root structures within the Goldlight Transitional Member suggest that the parts of the delta not occupied by active channels were normally submerged. The occasional occurrence of sustained mudstone within the Goldlight Transitional Member represents localised flooding, either where high lake levels inundated portions of the delta plain, or localised subsidence exceeded sediment supply.

Ward (1997) identified the deposition of the Goldlight Formation as being 'coincident with regional subsidence and basin-floor tilting, which was controlled by the now dominant NNE–SSW trending basin-bounding fault zones'. Development of the Goldlight Transitional Member was most likely due to a change in the tectonic conditions that had prevailed during deposition of the Goldlight MM. A decrease in intrabasin subsidence could have allowed sediment input to exceed the rate of accommodation, resulting in the change from lacustrine to deltaic conditions. Alternately a change in the basin margin uplift could have increased the volume of sediment being supplied to the basin, resulting in progradation of the alluvial plain and the infilling of the Goldlight Lake.

Figure 3.9 shows the approximate position and scale of the fault system identified by Ward (1997) as active during deposition of the Goldlight Formation. Comparison between the isopach maps of Dunollie and Goldlight Formations shows strong correlation between thickness patterns and the identified faults. The lack of coarse-grained material in the Goldlight Transitional Member and the correlation between thickness changes in the isopach maps and the fault pattern identified by Ward, favours control by changes in intrabasin subsidence. It is proposed that the change from Goldlight MM to Goldlight Transitional Member occurred due to a change in fault activity. Goldlight MM deposition appears to have been controlled by all of the faults in figure 3.9, with the major faults in the north and east dominating. However, deposition of the Goldlight Transitional Member appears to have been influenced mainly by the minor NNE–SSW trending fault set.

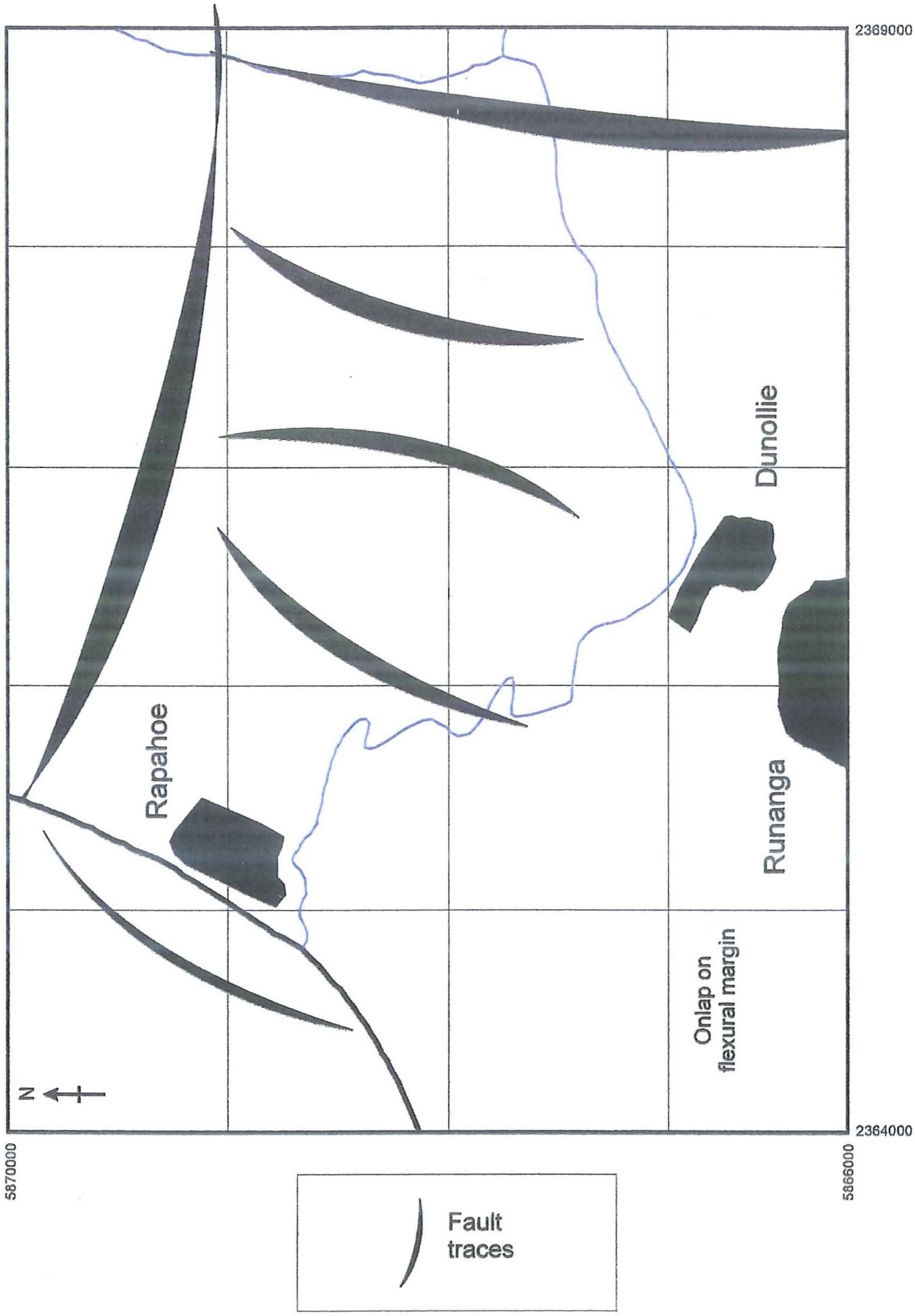


Figure 3.9: Tectonic controls active during deposition of the Goldlight Formation.

After Ward 1997.

Figure 3.10 provides a possible model of the development of the Goldlight Transitional Member and transition to deposition of the Dunollie Formation.

The model represented by figure 3.10 was produced from a combination of lithostratigraphic data. Unit distributions and thickness provided a depositional framework. Examination of the drillhole logs assisted in identification of zones of sediment transport. Areas where sand dominated over mud were considered more likely to contain major channels, while mud dominated areas were considered more likely to be between channels with deposition dominated by overbank flooding. Examination of relationships between the Goldlight MM and Goldlight Transitional Member and comparison of lateral variations in the relative thickness of the two members across the field area assisted in the identification of sediment sources and in the constraint of active fluvial pathways.

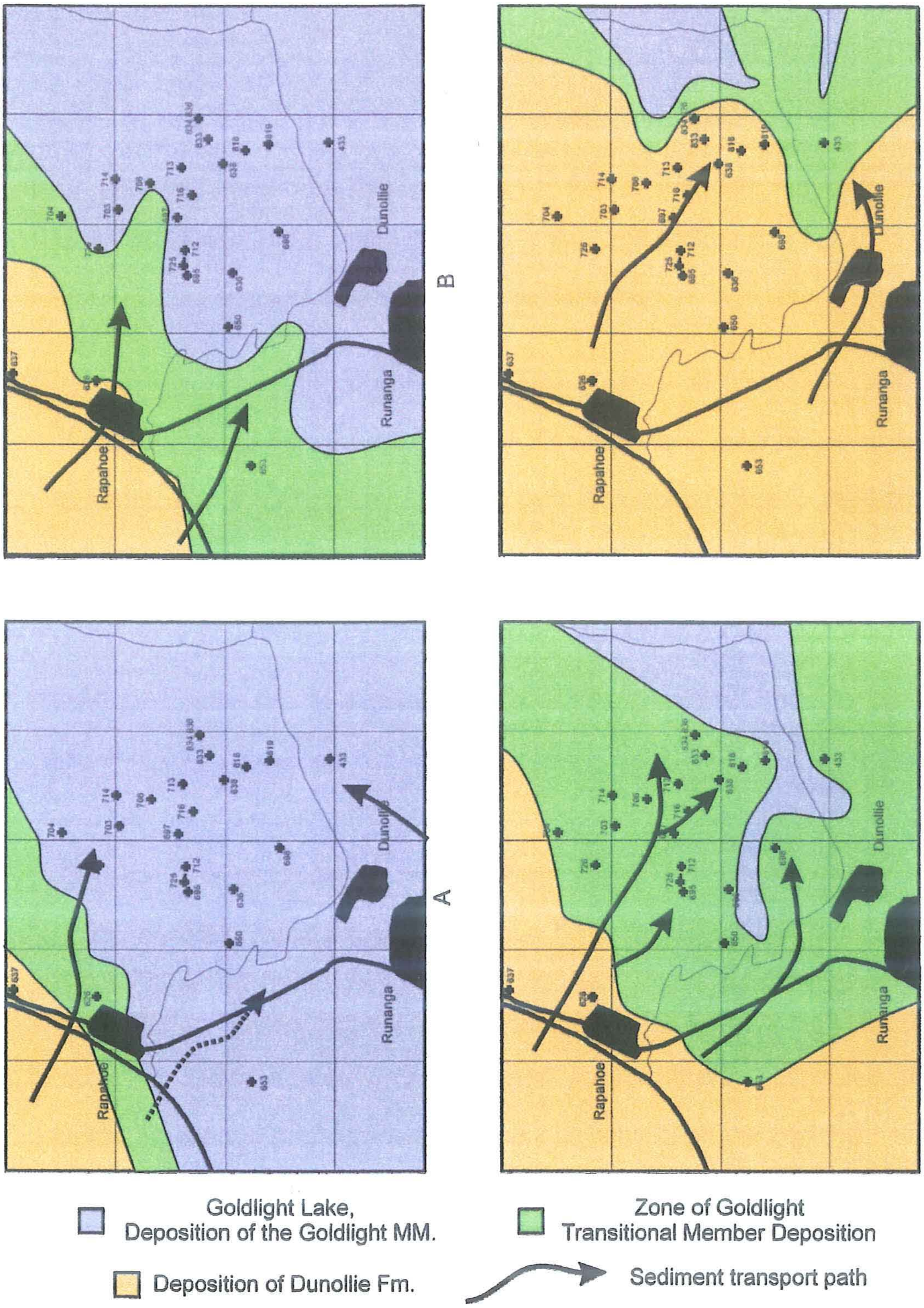


Figure 3.10 Proposed evolution of depositional environments from Goldlight MM to Dunollie Formation (the progression A – D is explained in detail in the text).

(A) Represents the distribution of depositional environments within the Southern Rapahoe Sector during deposition of the Goldlight MM. The Goldlight Lake dominated the region during the early Paleocene (Ward 1997). To the northwest the precursor to the Goldlight Transitional Member bounds the lake. Active sediment sources to the northwest have resulted in a conformable transition from Rewanui Coal Measure Member to Dunollie Formation.

(B) Decreasing accommodation within the Goldlight Lake or an increase in the supply of sediment from the northwestern source area resulted in progradation of deltaic facies into the Goldlight Lake. The initial delta development was focused around sediment point sources.

(C) Maximum extent of the transitional facies. The low angle of the delta plane combined with the fine-grained sediment resulted in frequent channel abandonment / diversion into interdistributary areas. Most of the Transitional Member was still sub-aqueous, but near shore the establishment of plants on the floodplain, combined with channel stabilisation and decreasing accommodation within the basin allowed the progradation of the Dunollie Formation from the west.

(D) Increased sediment supply or decreased accommodation within the basin, combined with the establishment of a floral community on the post-delta alluvial plain, resulted in a change from transitional lithosomes to deposition of Dunollie Formation coal measures. The Goldlight Lake still persisted to the southeast during early Dunollie sedimentation.

3.5.3 Dunollie Formation

The Dunollie Coal Measures accumulated as a low angle alluvial plain, which in the Southern Rapahoe Sector prograded over the Goldlight Formation from the western margin of the Paparoa Basin. The major change between deposition of the Goldlight Transitional Member to the Dunollie Formation was the transtion to a sub-aqueous environment and establishment of a floral community on the floodplain. Comparison between the isopach maps and the active faults (figure 3.9) suggest that the tectonic system continued to evolve during deposition of the Dunollie. Tectonic accommodation was focused to the north. The combination of active subsidence north of Rapahoe Township and a major fluvial system persistent since deposition of the Rewanui Formation resulted in the accumulation of thick relatively coarse Dunollie sediments (Ward 1997 pg. 131). South of Rapahoe Township accommodation continued on the small NNE-SSW fault system, however the rate of subsidence was relatively low compared to earlier activity on these faults.

In the lower portion of the Dunollie Formation mudstone and other overbank deposits dominate accumulation, this supports the proposal that the fluvial system was anastomosing (Smith and Smith 1980). Figure 3.11 provides an example of anastomosing channel deposit. This initial anastomosing fluvial system consisted of an interconnected network of low slope narrow, straight to sinuous channels transporting a mixture of fine to medium sand. Low islands of vegetated silt and clay separated channels. The anastomosing system is inferred to have developed as a response to slowing subsidence within the basin, resulting in the rapid aggradation of sediment on the previously sub-aqueous deltaic transitional facies (Smith and Smith 1980; Flores and Hanley 1984).

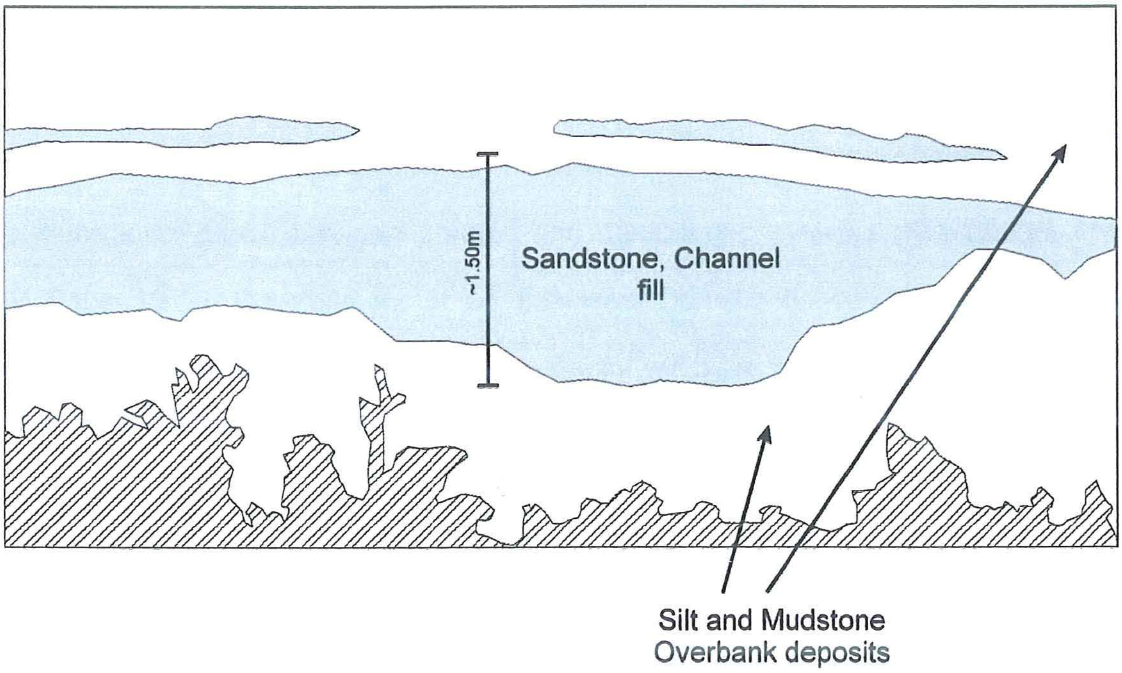


Figure 3.11: Anastomosing channel deposit from the lower Dunollie, Spring Creek Rd.

Rootlets, carbonaceous sediment and thin coal seams are relatively common interbedded with the overbank deposits, indicating that the inter-channel areas were heavily vegetated. Coal accumulation occurred in those areas with no direct connection to major channels where clastic sedimentation only took place during flooding or overbank spilling.

The deposits of the upper Dunollie are dominated by fine to medium cross-bedded sandstone, with minor interbedded mudstone. Overbank flooding was common depositing mud and fine sediment away from the stream channels. Leaf beds and abundant dispersed organic matter within the sediments indicate that vegetal growth upon the flood plain was abundant and contributing organic matter to the fine deposits (Allen 1965; Jackson 1981).

Anastomosing systems are often viewed as an unstable fluvial system that occurs as a transitional phase between braided and meandering systems (Kirschbaum and McCabe 1992). Development of an extensive Dunollie floodplain combined with reduced accommodation in the Rapahoe Sector will have reduced the gradient of the floodplain. A reduction in gradient within a fluvial system will increase the ratio of suspended sediment to bed load and may act to disrupt anastomosing fluvial systems (Tye et al 1999). Such a change in sediment transport is interpreted as destabilising the Dunollie anastomosing system, causing a transition to a meandering fluvial system.

The relatively low angle of the floodplain, hence relatively low energy within the fluvial system, resulted in the development of high sinuosity meandering stream system (figure 3.13). Deposition was dominated by the lateral accretion of point bars comprising fine to medium cross-bedded sandstones. This resulted in the deposition of widespread continuous sheets of sandstone within the upper Dunollie (figure 3.12).

Figure 3.12: Interbedded Sandstone and Mudstone in the upper Dunollie,

Spring Creek Rd.

The thickest bed in the centre of view is ~30cm thick.

As a meander system developed fines and organic matter can concentrated in cohesive and resistant clay plugs as they filled abandoned meander loops. These plugs act to confine the channel system (Shelton & Noble 1974, Flores 1981). Within the upper Dunollie most fines accumulated beside migrating channels due to overbank flooding. This resulted in the typical upper Dunollie outcrop pattern where sheets of cross-bedded sandstone are inter-bedded with sheets of mudstone and carbonaceous material (figure 3.12). However, the pattern and extent of coal occurrence in the upper Dunollie suggests that towards the end of Dunollie deposition a mechanism existed on the floodplain that prevented or reduced the occurrence of active channels within the southeast of the study area. It is proposed that the development of some resistive clay plugs to the north and west of where the upper Dunollie seam accumulated, diverted fluvial activity away from the developing mire.

Clay and organic infilling of meander loops within the Dunollie Formation resulted in the common association between carbonaceous horizons / thin coal seams and organic rich mudstones. Prior to abandonment, the very low energy meander loops may have been colonised by mire flora, accelerating the abandonment process and at the same time establishing mire conditions in isolation from the main channel (Hoorn, 1994).

Aside from normal lateral migration of the channel system, widespread disruption of the channels and flood plain occurred by avulsion of the channels during flooding, during which a new channel belt was established. Regional flooding leading to widespread avulsion of the fluvial system could have been caused by high rainfall within the source area overloading the capacity of the fluvial system. Smaller localised overbank spilling may have been caused by failure of the fine sediments within the channel banks, or the damming of channels by a more active deposition resulting in ponding and eventual overbank spilling.

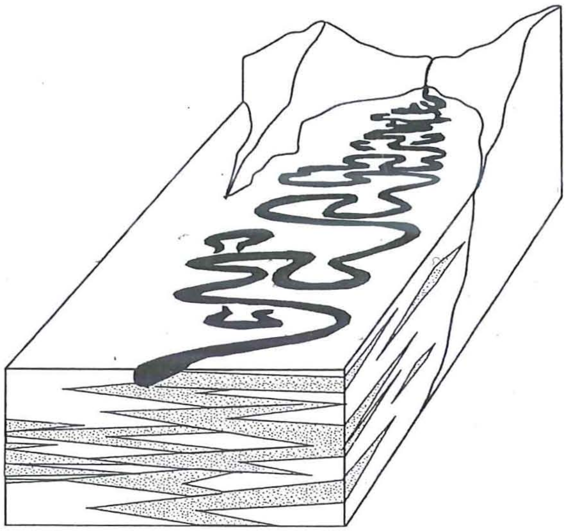


Figure 3.13: Simplified model of the style and geometry of deposits associated with high sinuosity meandering systems. After Allen 1965. Stippled areas represent channel deposits inter-bedded with the white overbank deposits

Based on coal seam occurrence and distribution confinement of the major channel to the northern portion of the field area late in the Dunollie, combined with waning tectonic accommodation within the basin resulted in the establishment of wide spread sustained mire conditions, especially within the southeast of the field area. This mire formed the upper Dunollie coal horizon.

3.5.4 Brunner Conglomerate Member and Brunner P

The transition from Dunollie Formation to Brunner Conglomerate Member is marked by an abrupt change from medium / fine sandstone and peat deposition to a rounded conglomerate consisting of quartz and Greenland Group clasts. This change is almost certainly due to a change in tectonic conditions. If the end of Dunollie accumulation had been caused by an increase in subsidence within the basin it is unlikely that the size of sediment being supplied to the basin would have increased so dramatically. Also, given the relatively low topography within the Paparoa Basin at the end of the Dunollie, a sudden increase in subsidence without an increase in sediment input, would have most likely resulted in the basin reverting to lacustrine conditions (Blair & Bilodeau 1988). It is more likely that the sediment source that had been active to the northwest throughout deposition of the Goldlight and Dunollie Formations experienced a temporary increase in tectonic activity. The resulting supply of coarse sediment flooded into the Paparoa Basin, overwhelming the existing fluvial system. Slowing of activity within the source area then returned the sediment supply to a condition similar to that present during deposition of the Dunollie Formation. The reduction in the size of sediment being supplied resulted in deposition of the Brunner P coal measures.

Erosion during uplift of the Paparoa Anticline has removed the Brunner P and Brunner Conglomerate Member from much of the study area. This lack of information means that producing isopachs or cross sections showing the detailed distribution of the Palaeocene Brunner is not possible. However it is certain that the Brunner Conglomerate Member prograded from the northwest, as the conglomerate becomes finer and sandier and quartz dominated to the south and east.

3.5.5 Summary and Conclusions

Deposition within the upper units of Paparoa Coal Measures varied in response to a combination of tectonic controls, both intrabasinal and regional. Basin accommodation was driven by orthogonal or transtensional extension of the basin (Ward 1997). The type and volume of sediment supplied to the Rapahoe Sector part of the basin was primarily dependent on tectonic activity in a northwestern source area. Plant life within the basin acted to stabilise deposition and bind fines as well as contributing organic material to the sediments, forming plant beds and coal seams.

The transition from Rewanui Formation to Goldlight Formation is attributed to increased subsidence within the basin resulting in lacustrine conditions. The decrease in base level within the basin resulted in a reversal of axial drainage trends with sediments being reworked and deposited northward into the Goldlight lake (Ward 1997). The focus of tectonic activity then shifted. Sediment supply and subsidence within the Rapahoe Sector became centred north of Rapahoe Township. Slowing tectonic accommodation within the southern portion of the basin allowed the persistent influx of sediment from the northwest to overtake subsidence, resulting in the progradation of a deltaic transitional facies across the basin. These deltaic deposits form the Goldlight Transitional Member. Further reduction in accommodation in the southern portion of the field area allowed for emergence of a floodplain and the transition from lacustrine to fluvial conditions. The transition from lacustrine to fluvial conditions was aided by stabilisation of the emergent sediments by plants. With the establishment of plant life on the floodplain increased organic material was included in the sedimentary deposits, these deposits form the Dunollie Coal Measures.

The initial floodplain fluvial system took the form of an anastomosing system in response to the tectonic and sedimentary conditions. Mudstone and carbonaceous material dominate lower Dunollie deposits formed by overbank flooding in the anastomosing fluvial system. Sandstones are confined to vertical channel accumulations and limited lateral accretion from point bars. Deposition of thin coal seams occurred due to mires occupying the isolated portions of inter-channel deposits. It is the presence of these mires and the dispersed carbonaceous material from the inter-distributary vegetation that provides one of the boundary conditions between the Dunollie Formation and the underlying Goldlight Transitional Member (Chapter 2).

A gradual reduction in floodplain gradient in the mid – late Dunollie produced an increase in the ratio of suspended load to bed load within the fluvial system, destabilising the anastomosing system. The Dunollie fluvial system changed to a meandering system in response to these new conditions. The meandering system deposited relatively continuous sheets of sandstone, deposited as point bars migrated across the floodplain and down-stream. Development of mires within the meandering fluvial system allowed for the inclusion of organic rich beds and thin coal seams within the sequence. Increasing confinement of the fluvial system permitted thick peat accumulation towards the end of Dunollie deposition. Increased regional tectonics then supplied coarser and greater volumes of sediment into the relatively full basin, resulting in rapid progradation of conglomerates across the floodplain terminating deposition of the Dunollie Formation. Though intense this upswing in regional activity was relatively short lived. Medium to fine sand was once again the dominant sediment supplied to the basin, resulting in deposition of the Brunner P.

Chapter 4

Coal Properties

4.1 Introduction

A complex interaction of physical and chemical factors within the mire affects the final properties of any coal produced. Although a single coal property may provide some insight into mire conditions, the reliability of the interpretation increases as more properties are considered and accounted for in the paleoenvironmental model. Hence reconstruction of paleomire conditions from coal properties requires the synthesis of as many and as diverse coal properties as possible, in order to provide as complete a reconstruction as possible.

To this end this chapter is divided into three sections

- Petrology
- Chemistry
- Palynology

Each section provides an introduction detailing the reasons for examining a particular coal property, the method of sample collection and analysis, results, and discussion of trends and possible conditions or changes within the mire that they represent.

The final section of this chapter is a synthesis of the sub sections, examining how changes in one group of coal properties affects other properties, and producing a model of paleomire conditions and how they changed over time.

4.2 Petrology

4.2.1 Introduction

Coal petrology is widely used in the assessment of paleoenvironment. Maceral analysis provides an indication of the processes acting within the mire. Environmental conditions that can be determined from petrographic analysis include:

- Mire drainage; is the accumulating peat below the water table or are there dry periods where the peat is exposed and oxidised. Was the mire periodically invaded by floodwater carrying clastic minerals and transported organic material
- Mire chemistry; pH low (acid) or high (alkaline, e.g. marine influence)
- Were fungal and bacterial agents at work in the peat and how active were they.
- What types of plant tissue formed the peat, i.e. woody vs. leafy material, gymnosperm or angiosperm and are there any unusual or distinctive plant remains.

4.2.2 Methods

4.2.2.1 Sampling

Collection of new samples was restricted to coal exposures in either outcrop or mine workings. Due to the limited amount of the drillhole material, no subsurface sampling from drillholes was undertaken. However, subsurface petrology data has been included from the analyses performed by K. Brown (1994).

Material collected can be divided into four categories.

1: Block samples collected in the field from surface coal outcrops and from the portal openings of abandoned mine workings (e.g. New Point Elizabeth Mine)

2: Samples collected by R. Boyd during field investigations for Greymouth Coal Ltd. These include samples from within abandoned mine workings and isolated seam exposures from some of the normally less accessible parts of the study area.

3: Material collected during mine operation of the Birchfields Opencast. These samples were collected and mounted during the mid 80's. Retrieved from storage in the University of Canterbury's Department of Geologic Sciences, these samples were mounted in larger blocks as required by modern polishing equipment and re-polished.

4: Data from K. Brown's (1994) investigation of the Dunollie. This data took the form of seven maceral analyses of Brunner and Dunollie coals from DH 698.

4.2.2.2 Petrographic analysis

Two kinds of petrographic analysis were performed.

1: Standard petrographic analysis of polished blocks in oil immersion.

2: Examination of etched blocks, to facilitate differentiation of vitrinite macerals and identification of fine cellular detail.

Sample preparation is described in detail in Appendix 2. All of the mounted block samples underwent standard maceral analysis. Maceral analysis was performed using a Leitz incident light microscope, at 500x magnification with oil immersion. Sample blocks were mounted so that all traverses occurred perpendicular to bedding, with a point spacing of 1 mm. A total of 500 points were counted and identified on each block using a Swift Model F Automatic point counter. This total was reduced to 400 points for samples where the mounted material was insufficient to complete a full count of 500 points.

Fifteen types of maceral and mineral matter were identified within the coals as detailed in Table 4.1. Identification of macerals was made according to the criteria of the International Committee for Coal Petrography (1971) and Stach et al. (1982), with reference also to Falcon and Snyman (1986).

Blocks that in oil immersion appeared to consist entirely of undifferentiated vitrinite were placed aside for etching and re-examination. Etching reveals fine cellular details and facilitates differentiation of vitrinite macerals and was completed using the following method. The polished blocks were carefully washed with ethanol and a weak detergent solution in order to remove all of the immersion oil. The blocks were then etched for 5 to 10 seconds with a boiling solution of 25 g potassium permanganate and 5 ml sulphuric acid in 100 ml of water. The blocks were then cleaned in a solution of 25 g sodium sulphite and 5 ml sulphuric acid in 100 ml of water. The blocks were then examined using the Leitz incident light microscope in air. This method is after Stach et al (1982), and has been used on New Zealand coals by a number of people, including Newman, J. (1988), Shearer (1992) and Hayes (1999).

4.2.3 Results

The petrology results for block samples examined in oil immersion appear in Table 4.1. The results were used to compare the petrology of Dunollie and Brunner P coal seams. Results for Dunollie samples were also used to define the changes in petrology vertically within the Dunollie Formation and within individual seams. Petrology data was also used as a tool to assist in the correlation of seams.

Sample Number	CN1	CN1	CN1	CN1	CN1	CN1	CN1	CN1	CN6	CN6	CN6	CN6	CN7	CN8
	3.10	2.65	2.30	1.95	1.65	1.20	0.90	0.70	S1	S2	S3 upper	S3 lower		
Formation Sampled	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Vitrinite Group														
Telocollinite	41.4	38.8	37.8	55.2	33.2	33.4	52.2	53.6	55.8	54.8	54.4	34.8	1.6	0.3
Desmocollinite	35.8	34.3	46.6	32.0	50.2	47.6	36.0	33.8	30.8	31.6	30.8	39.0	96.2	99.0
Corpocollinte	0.0	2.8	0.2	0.0	0.8	1.2	0.6	0.0	1.0	0.2	0.6	0.0	0.8	0.0
Mineral Matter														
Clay	2.6	6.0	1.6	0.6	0.8	0.4	1.0	0.0	0.2	0.6	0.8	15.8	0.6	0.0
Quartz	0.0	0.8	0.8	0.0	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Pyrite	4.0	0.5	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.0	0.0	0.0	<0.1	0.0
Inertinite Group														
Fusinite	0.2	0.0	0.2	0.6	0.0	0.4	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Semifusinite	0.2	0.0	0.4	0.2	0.6	0.2	1.2	0.4	1.0	0.8	0.8	0.0	0.0	0.0
Inertodetrinite	0.0	0.5	1.8	1.0	0.6	0.8	0.6	0.2	0.4	1.0	0.6	0.5	0.0	0.0
Sclerotinite	0.4	1.5	1.8	1.4	4.2	3.6	1.6	1.0	2.2	0.2	2.0	0.0	0.0	0.0
Liptinite Group														
Resinite	5.2	13.5	5.2	3.6	4.2	4.6	0.0	4.8	1.8	0.4	2.8	5.5	0.0	0.0
Suberinite	3.2	0.3	0.8	3.0	1.4	2.4	1.0	1.8	2.4	5.0	1.2	0.8	0.2	0.0
Cutinite	1.0	0.3	0.8	1.8	0.6	2.0	4.6	3.6	2.6	2.8	1.8	0.8	0.4	0.3
Liptodetrinite	6.0	1.0	2.0	0.6	2.6	2.8	0.4	0.4	0.8	2.4	4.2	2.8	0.2	0.3
Sporinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.2	0.0	0.0	0.0	0.0
Total Vitrinite	77.2	75.8	84.6	87.2	84.2	82.2	88.8	87.4	87.6	86.6	85.8	73.8	98.6	99.3
Total Inertinite	0.8	2.0	4.2	3.2	5.4	5.0	4.2	1.8	3.6	2.0	3.4	0.5	0.0	0.0
Total Liptinite	15.4	15.0	8.8	9.0	8.8	11.8	6.0	10.6	8.6	10.8	10.0	9.8	0.8	0.7
Total Mineral Matter	6.6	7.3	2.4	0.6	1.6	1.0	1.0	0.2	0.2	0.6	0.8	16.0	0.6	0.0

Notes

Formation Sampled D = Dunollie

B = Brunner P

Table 4.1: Point Counts of Petrology Samples. Values expressed as percentages

Sample Number	CN9	CN10	CN13	CN18	CN19	CN20	CN21	CN22	CN B1	CN B2	CN B3	CN B5	CN B6
Formation Sampled	D	D	D	D	D	D	D	D	B	B	B	B	B
Vitrinite Group													
Telocollinite	35.0	28.6	29.0	43.8	24.0	40.0	33.0	50.3	65.8	62.2	61.2	66.4	63.8
Desmocollinite	48.6	53.0	57.6	48.4	53.8	46.4	58.2	43.0	22.8	22.2	26.8	25.6	21.2
Corpocollinte	0.2	1.8	1.2	0.6	0.2	0.4	0.4	1.0	1.2	0.8	1.0	0.2	0.2
Mineral Matter													
Clay	10.6	3.2	0.6	0.0	0.2	0.0	0.0	0.0	0.6	0.0	0.8	0.0	0.0
Quartz	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pyrite	0.0	0.0	0.0	0.0	0.4	0.0	0.6	0.0	0.4	0.6	0.0	0.0	1.6
Inertinite Group													
Fusinite	0.6	0.2	0.0	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Semifusinite	0.2	0.8	1.0	0.2	0.2	0.2	0.0	0.3	0.0	0.0	0.2	0.0	0.0
Inertodetrinite	0.0	0.0	0.2	0.0	1.2	0.2	0.0	0.0	0.0	0.4	0.2	0.0	0.0
Sclerotinite	0.2	0.0	1.2	0.2	4.8	2.0	2.6	0.8	0.2	0.8	0.0	0.0	0.0
Liptinite Group													
Resinite	1.0	7.2	0.2	0.6	6.2	2.6	0.2	0.3	3.2	6.0	4.4	6.2	11.2
Suberinite	1.6	1.0	3.6	0.0	0.0	0.0	0.0	0.0	1.8	1.2	0.2	0.2	0.4
Cutinite	0.4	1.6	4.0	4.4	2.0	2.0	1.2	2.5	0.6	0.4	2.4	0.4	0.4
Liptodetrinite	1.6	1.6	1.4	1.2	3.4	2.2	1.4	1.8	3.4	5.4	2.8	1.0	1.0
Sporinite	0.0	1.0	0.0	0.4	3.6	3.0	2.4	0.3	0.0	0.0	0.0	0.0	0.0
Total Vitrinite	83.8	83.4	87.8	92.8	78.0	86.8	91.6	94.3	89.8	85.2	89.0	92.2	85.2
Total Inertinite	1.0	1.0	2.4	0.6	6.2	2.8	2.6	1.0	0.2	1.2	0.4	0.0	0.2
Total Liptinite	4.6	12.4	9.2	6.6	15.2	9.8	5.2	4.8	9.0	13.0	9.8	7.8	13.0
Total Mineral Matter	10.6	3.2	0.6	0.0	0.6	0.6	0.6	0.0	1.0	0.6	0.8	0.0	1.6

Notes

Sample CN B4
Destroyed during
polishing process

Sample Number	Birchfields	Birchfields	52/172	52/174	52/175	52/176	52/177	52/178	52/179
	Base	Top -1m	DH 698	DH 698	DH 698	DH 698	DH 698	DH 698	DH 698
Formation Sampled	B	B	B	B	D	D	D	D	D
Vitrinite Group									
Telocollinite	48.6	29.2	33.8	38.8	32.0	6.8	40.0	20.2	40.4
Desmocollinite	43.4	39.0	53.0	42.8	45.2	83.2	53.8	73.8	37.4
Corpocollinite	0.0	0.8	0.0	3.8	3.0	0.0	0.0	0.0	4.0
Mineral Matter									
Clay	0.0	0.0	5.4	1.6	1.6	0.0	1.2	0.4	1.8
Quartz	0.2	0.0	0.6	0.2	0.2	0.0	0.0	0.0	0.2
Pyrite	0.0	0.0	0.0	1.2	0.2	0.0	0.0	0.0	0.0
Inertinite Group									
Fusinite	0.0	0.4	0.0	0.0	1.8	0.0	0.0	1.0	0.4
Semifusinite	0.0	0.0	0.2	0.0	1.6	0.0	0.2	0.4	0.2
Inertodetrinite	0.0	0.0	0.2	0.6	3.0	1.2	0.2	0.6	1.8
Sclerotinite	0.0	0.6	0.0	0.6	0.4	4.2	0.6	0.0	1.2
Liptinite Group									
Resinite	3.6	3.6	1.0	2.4	4.4	0.6	0.6	0.2	2.4
Suberinite	0.2	0.0	1.0	2.0	3.0	0.0	1.8	0.6	3.4
Cutinite	1.6	2.0	0.0	2.0	0.4	0.0	0.0	0.0	0.0
Liptodetrinite	2.4	4.4	4.8	3.6	2.6	3.0	1.4	2.6	5.4
Sporinite	0.0	0.0	0.0	0.4	0.6	1.0	0.2	0.2	1.2
Total Vitrinite	92.0	86.3	86.8	85.4	80.2	90.0	93.8	94.0	81.8
Total Inertinite	0.0	1.3	0.4	1.2	6.8	5.4	1.0	2.0	3.6
Total Liptinite	7.8	12.5	6.8	10.4	11.0	4.6	4.0	3.6	12.4
Total Mineral Matter*	0.2	0.0	6.0	3.0	2.0	0.0	1.2	0.4	2.0
Notes			JN	KB	KB	JN	JN	JN	KB

JN: Analysed by J. Newman KB: Analysed by K. Brown

* For samples 52/172 - 52/179 mineral matter values may be elevated due SG segregation of minerals during mounting

Examination of the blocks subjected to the etching process revealed no new significant features. It is concluded that the samples consisted almost entirely of desmocollinite, hence there is no additional data relating to the etched samples that is not included with the normal petrology data.

Tissue Preservation Indices (TPI) were calculated from the petrology data using the formula:

$$\text{TPI} = \frac{\text{telocollinite}}{\text{desmocollinite} + \text{vitrodetrinite} + \text{corpocollinite*}}$$

* Corpocollinite as used here is only that material that occurs as isolated bodies and not corpocollinite that occurs within cell walls.

TPI results are shown in Table 4.2.

Sample Name	TPI	Sample Name	TPI	Sample Name	TPI
CN1/0.70	1.59	CN/9	0.72	Birchfields Base	1.12
CN1/0.90	1.43	CN/10	0.52	Birchfields: 1m Below Roof	0.73
CN1/1.20	0.68	CN/13	0.49	52/172	0.64
CN1/1.65	0.65	CN/18	0.89	52/174	0.83
CN1/1.95	1.73	CN/19	0.44	52/175	0.66
CN1/2.30	0.81	CN/20	0.85	52/176	0.08
CN1/2.65	1.05	CN/21	0.56	52/177	0.74
CN1/3.10	1.16	CN/22	1.14	52/178	0.27
CN6/S1	1.75	CN B1	2.74	52/179	0.98
CN6/S2	1.72	CN B2	2.70		
CN6/S3U	1.73	CN B3	2.20		
CN6/S3L	0.89	CN B5	2.57		
CN7	0.02	CN B6	2.98		
CN8	0.00				

Table 4.2 Tissue Preservation Indices

Coals from the Dunollie Formation are dominated by macerals from the vitrinite group. Vitrinite generally accounts for 80 to 90 percent of the macerals identified, with minor inertinite and liptinite making up the remainder. Mineral matter is generally low making up approximately 1~2% of the points identified. A small number of samples have mineral matter ~15%. Within the vitrinite group the proportions of telocollinite and desmocollinite each fluctuate between 35 and 60 percent of total. There are two extreme cases (samples CN7 and CN8) where desmocollinite comprises >95% of the sample. These samples were etched and re-examined after which they still appeared to comprise unstructured vitrinite with little or no differentiation within the sample.

Variations in total maceral group proportions are largely the result of changes in the abundance of liptodetrinite and resinite. The maceral analysis does not include any subdivision of the resinite maceral group, however in hindsight a distinction between normal resin and resin that fluoresces green in white light (fluorinite) could have been made. It is recommended that future investigation of these and similar coals should consider such a division. An example of a fluorinite maceral is given in figure 4.1. A qualitative assessment indicates that the proportion of fluorinite is greatest when resinite is abundant within a sample. For example, sample CN1/2.65 has abundant resinite (13.5%) and fluorinite dominates over "normal" resinite. By contrast sample CN1/1.95 has far less resinite (3.6%) and fluorinite comprises only a small proportion of this material. Resinite typically occurs in bands orientated parallel to bedding. In some samples multiple 'blebs' of resinite form a layer extending across most of the sample. The resinite layers are often associated with elevated clay content and vitrodetrinite. These resinite and clay layers can often alternate with layers of clean structured vitrinite.

Inertinite is relatively scarce, seldom exceeding 5% of total maceral occurrence. Structurally competent fungal spores dominate the inertinite fraction, hence sclerotinite is the most common maceral within the inertinite group.

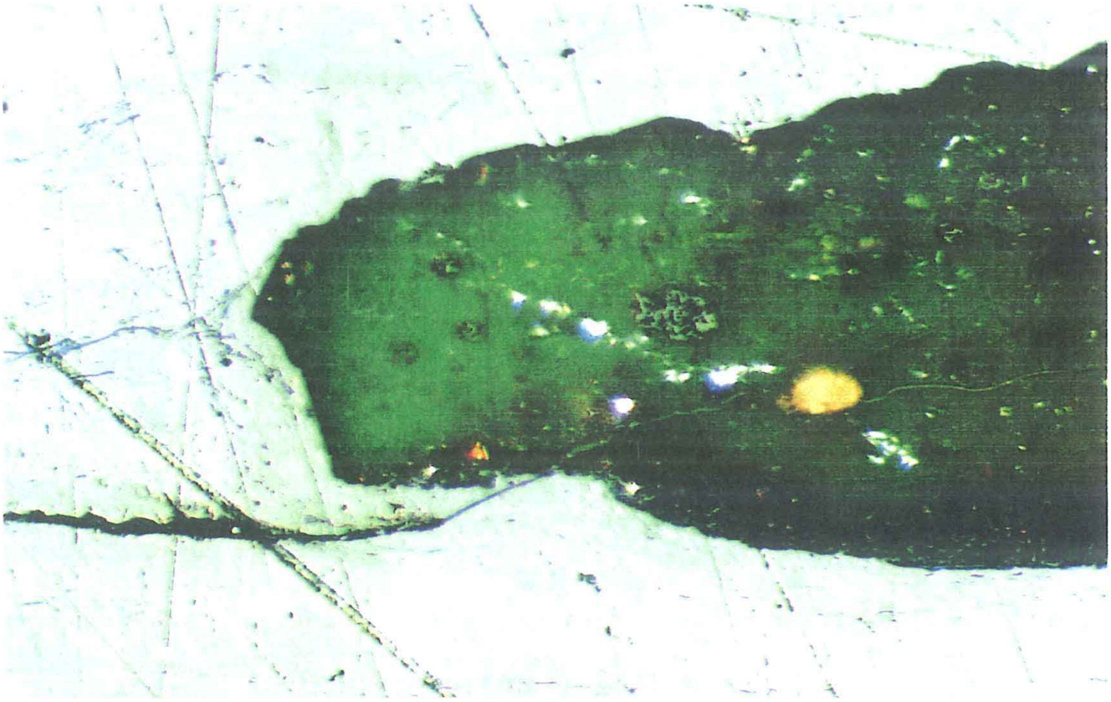


Figure 4.1: Fluorinite maceral in Dunollie coal.

4.2.4 Discussion

The association of resinite, with clay minerals in laminae, suggests that a portion of the resinite may have been allochthonous in origin. Buoyant resinite could have floated into the mire during flooding events. As the water level within the mire subsided to normal levels, floating resinite and suspended clay minerals would accumulate as a layer on the peat. Newman (1987) and Stach et al (1982) have associated the occurrence of fluorinite with a particular coniferous floral assemblage. Newman suggested that some coniferous flora require a relatively abundant nutrient supply, resulting in growth normally near streams carrying sediment. Newman's suggestion was made based on examination of coals from the upper Rewanui Formation, within which a distinctive assemblage of waxy and resinous macerals was identified often in association with clastic minerals. The concentration of fluorinite and associated macerals within the Dunollie supports this hypothesis.

Examination of some resinite macerals reveals degradation of their outer margins as if they have been weathered or subjected to microbial activity. This is consistent with the concept that at least some of the macerals were transported. An example of this is shown in figure 4.2.

It is suggested here that a particular coniferous flora occurred around the margins of Dunollie mires. During flooding of the mire this coniferous flora acted as a source of fluorinite macerals, which were floated into the accumulating peat along with clastic sediments. During normal mire conditions no mechanism existed to transport the fluorinite from the mire margins. Rare occurrences of fluorinite within clean vitrinite suggest limited incursion of these conifers may have occurred into the central mire flora, despite the low nutrient conditions.

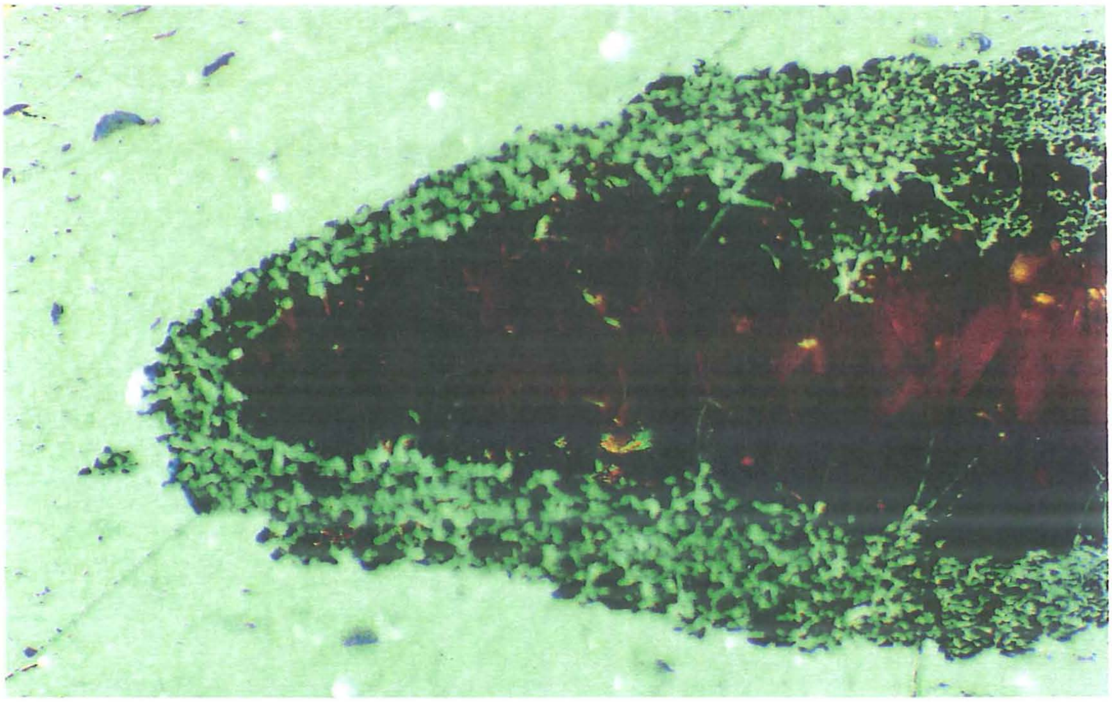


Figure 4.2: Resinite maceral showing degradation of margin

Fluorinite occurrence has been associated with liquid hydrocarbon generation within Tertiary coals (Mishra & Ghosh 1996). Problems with oil leakage from blocks as described in Appendix 2, indicate that some hydrocarbon generation has occurred within the Greymouth Coalfield. Generation within the Dunollie Formation is unlikely given the relatively low rank of the organic matter. Generation may have occurred in the lower Paparoa formations or to the south where the plunging Paparoa Anticline allows for greater burial of the upper formations. Hydrocarbons could then have migrated. Alternatively a predisposition of fluorinite for early generation may assist in explaining the presence of hydrocarbons within the upper sequence, as limited generation may have been possible at low ranks / temperature.

Sclerotinite is also often found in layers lying parallel to bedding, associated with a mixture of desmocollinite, telocollinite and liptodetrinite. Unlike resinite these layers show no strong relationship to the occurrence of clastic material. This suggests that sclerotinite was produced during times of normal or lowered water table within the mire. At these times the peat surface may have been exposed to the air and subject to microbial attack. Alternatively some elements of the living mire flora may have periodically experienced fungal attack (as is common in the case of modern Manuka) (Shearer 1992).

Tissue preservation can be related to peat acidity, water levels, oxygen access and the floral community within the mire. For example a low pH inhibits bacterial and fungal activity, resulting in greater preservation of cellular material. Water table within the mire also plays an important role. Exposure of the peat due to low water levels will allow oxidation and degradation of the peat surface to occur.

Lignin is a substance found in plant cells, which undergo secondary cell wall development. The purpose of lignin is to provide physical strength and resistance to microbial decay. During the Tertiary, dominant mire plants included both angiosperms and gymnosperms. The lignin of these plant groups differs compositionally. Angiosperms possess syringyl / guiacyl lignin, whereas gymnosperms possess guiacyl lignin. The angiosperm form of lignin is considerably more degradable under mire conditions (Shearer & Moore 1994a). This results in a predisposition of angiosperm material to degrade far more readily than gymnosperm tissue. Hence, coals composed of material derived wholly or in part from angiosperms will be likely to have lower TPI values than those formed from gymnosperm material (Shearer et al 1995).

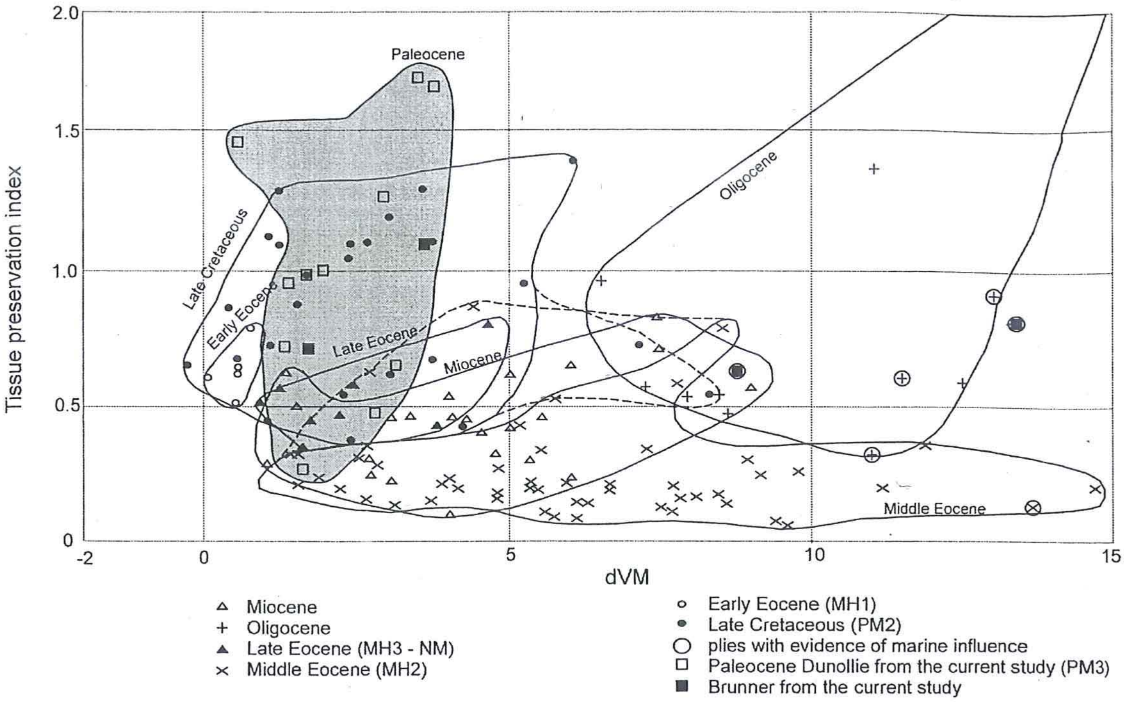


Figure 4.3 Relationships between Tissue Preservation Index and delta Volatile Matter, Cretaceous – Tertiary Coals, New Zealand. After J. Newman (1989) Marine influenced plies have been omitted from the shaded area.

Figure 4.3 relates the coals examined in this study to a range of New Zealand coals investigated by Newman (1989). The Paleocene division shaded in figure 4.3 is newly derived, and represents the PM3 palynological division. In terms of TPI and dVM the coals of the Dunollie and Brunner P most closely resemble those of the Late Cretaceous.

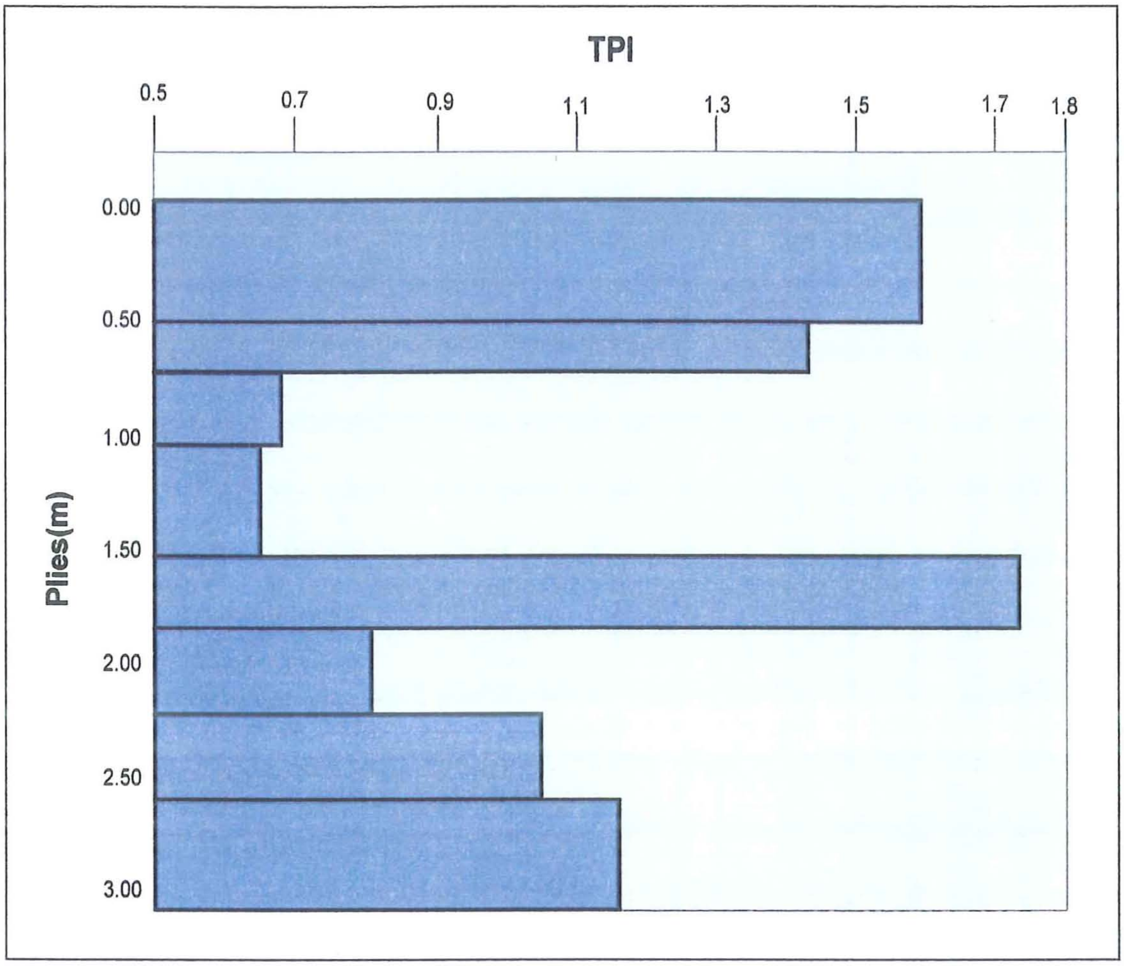


Figure 4.4: Tissue Preservation Indices for plies of seam CN1

Figure 4.4 is a graph of TPI values for the thickest Dunollie seam sampled (CN1 samples from the New Point Elizabeth Seam, after Appendix 1); TPI clearly varied during the life of the mire.

Initially moderately high TPI values for the lower plies indicate that some factor or combination of factors was acting within the mire to minimise tissue decay within the accumulating peat. For example a consistently high water table within the developing mire would have aided peat preservation. The initial flora within the mire may also have been more robust due to higher nutrient levels when compared to vegetation later in the mire history (Moore 1996), leading to a good preservation of cellular material.

In terms of mire flora the palynology data from section 4.4 indicates that both angiosperms and gymnosperms were available to colonise the mire. The mire flora appears to have changed during the life of the mire, angiosperm pollen accounts for ~58% of the pollen recorded from the bottom of the seam, while in the middle and upper portions of the seam angiosperm pollen accounts for ~10% of the total palynomorphs. This may indicate that growth conditions were easier while the mire was first forming. Later when the mire was fully established harsher conditions such as poor nutrient supply favoured plants, which were specialised for mire conditions, a niche dominated at the time by gymnosperms. The unusual correlation of high angiosperm abundance with high TPI at the onset of mire development indicates that lignin chemistry was not a significant factor. The highest abundance of resinite occurs in the lower portion of the seam, and the average mineral matter content is also relatively high compared to the rest of the seam. This suggests that flooding was common during initial mire development. Hence it is proposed that a combination of high water table and robust vegetation are responsible for the initially high TPI.

Later development of better drainage within the mire could have lowered the water table, encouraging oxidation and microbial degradation. Nutrient availability may also have declined as the mire became more extensive and the peat layer thickened. Under low nutrient conditions the mire flora may have been less robust and more prone to decay, resulting in poorer preservation of tissue within the peat. These suggestions are consistent with trends in TPI and the low mineral matter content. The central NPE may have formed under conditions similar to some modern Indonesian peats (Grady et al 1993). As similar trends in mineral content and tissue preservation have been reported from thick peat deposits where water table and vegetation tissue strength are controlling the structure of the accumulating peat.

High TPI values late in the mire's life may represent an increased acidity of the mire ground water, and / or an elevated water table. The moderate increase in ash content in the upper plies indicates increased flooding and is more consistent with a high water table than high acidity. The uppermost portion of the seam was not sampled for palynological investigation so it is currently impossible to say what happened to the floral community in the last stages of mire existence.

Therefore, while a number of factors can affect tissue preservation, TPI within the New Point Elizabeth Seam is considered likely to have been controlled primarily by water table and nutrient supply. A high water table will have kept the peat wet while flooding will also have increased nutrient availability allowing for the growth of more diverse and robust plants. As the mire developed the water table may have been more varied. Stream activity was constrained resulting in reduced nutrient supply and less flooding of the peat.

The majority of samples from Dunollie seams (CN1 – CN22) have relatively low TPI. Although average TPI is 0.99 overall, when samples from the major upper Dunollie seam occurrence are excluded the average TPI drops to 0.45. Low TPI for the majority of Dunollie seams can be attributed to the conditions under which they formed. Dunollie seams with low TPI values are all very thin, generally not more than 30 cm. maximum thickness. These thin seams represent mires that only barely became established upon the Dunollie floodplain. Interbedding with mudstones is common, and the coals often grade into mudstone bounding units. All of these factors point to relatively unstable mire conditions. Peat accumulation was subject to flooding and probably a fluctuating water table. The flooding events and common introduction of fresh water will have kept the peat wet, but they will also have oxygenated the mire, and prevented the development of acidic conditions. The combination of oxygenation and relatively high pH will have allowed microbial activity to flourish, degrading the peat and destroying cellular structures.

Of the samples from thin seams, CN7 and CN8 stand out as unusually degraded, with TPI values of 0.02 and 0.00 respectively. Both of these samples came from exceptionally thin seams (<20 cm) made up of multiple thin coal horizons interbedded with mudstone and sandstone. Resinite is completely absent from these samples. While the coal samples have very low concentrations of mineral matter the environment of accumulation must be considered nutrient rich due the interbedded mudstones and proximity of sediment beneath the peat. The low TPI and absence of resin suggest that the distinctive conifer floral assemblage identified in other seams was absent. In addition to oxygenation and pH it is possible that there were floral controls on TPI, but this cannot be determined directly due to the absence of palynological data for these seams.

In contrast to the Dunollie coals those sampled from the Brunner P have relatively high tissue preservation indices. These samples comprise of CN B1-6 (a series of samples from a single seam in the south west of the field area), the two samples previously obtained from Birchfields Opencast (BF base and BF Roof –1m) and 52/172 and 52/174. TPI for the Brunner P samples ranges from 0.73 to 2.98 with a median value of 2.57. This result may however be in part, an artefact of the relatively limited Brunner sampling. High TPI values are restricted to samples CN B1-6, which represent a single seam. Palynological analysis of Brunner material (Chapter 4.4) shows an increase in the abundance of angiosperms relative to gymnosperms, and a lower occurrence of Gleichenia spores when compared to Dunollie samples from the same drillhole. If the high angiosperm content contributed organic matter more susceptible to degradation as proposed by Shearer & Moore (1994a), depositional conditions must have acted to counteract this predisposition towards decay.

Figure 4.5 provides a summary diagram of petrological parameters and then lists the possible environments within which the peat accumulated.

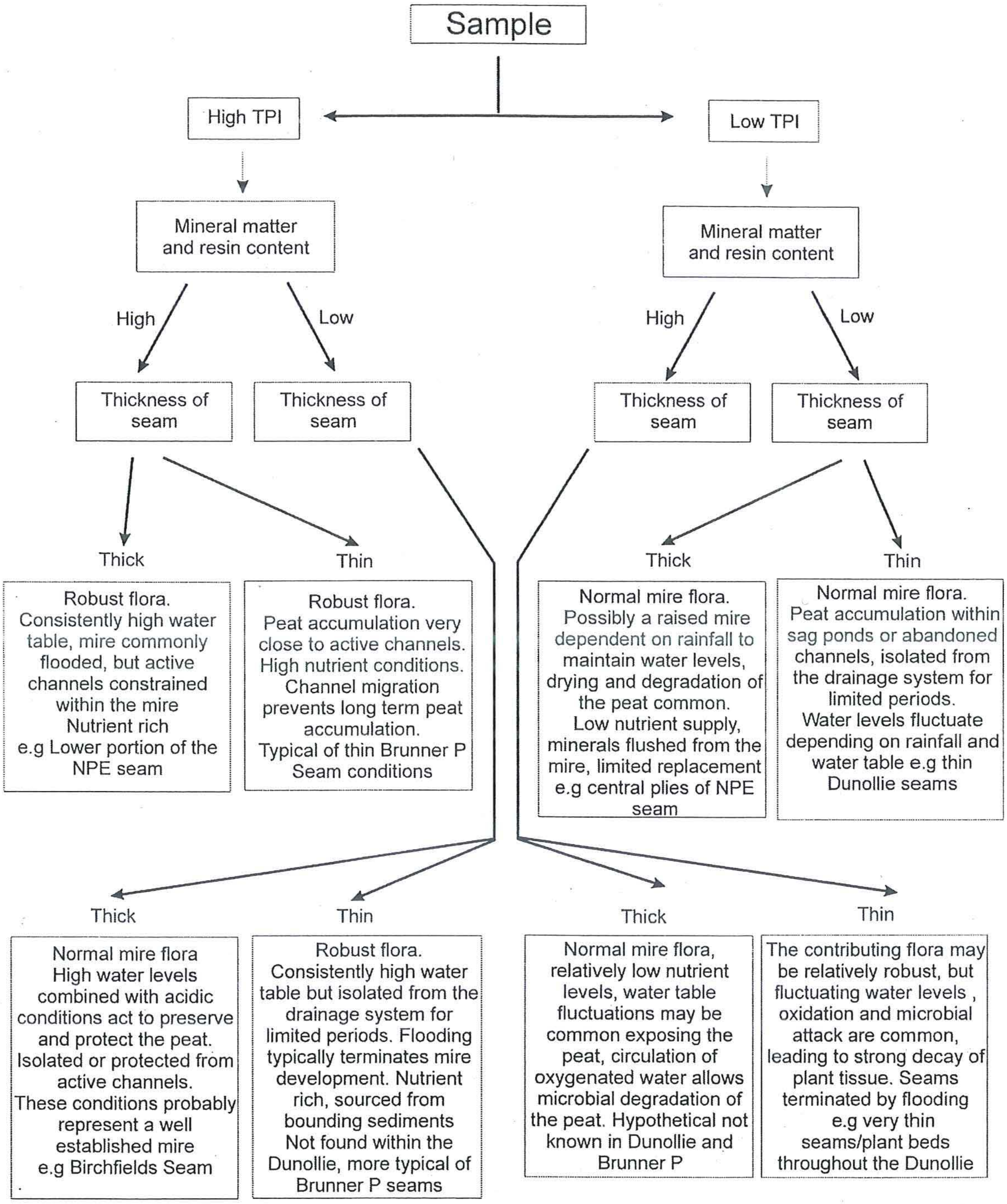


Figure 4.5 summary of petrologic properties and potential formation environments

4.3 Chemistry

4.3.1 Introduction

Chemical analysis provides information on moisture, ash content, volatile matter, sulphur and energy content of the coal. These chemical properties provide a range of parameters for assessing mire character because environmental conditions within the mire influence peat chemistry and mineralogy. For example, the ash content of a coal provides an indication of flooding. In this study coal chemistry is used for interpretation of paleomire conditions as well as seam correlation.

4.3.2 Methods

Data for this part of the study were obtained as follows:

1: Ply samples collected as part of the field investigation. Where seam thickness was less than 50cm the seam plies were combined into a single sample prior to chemical analysis.

2: Historic information, i.e. chemical data from past mining and scientific studies. Includes data from mining at Birchfields Opencast, Tiller and New Point Elizabeth Mines and research data from K Brown (1994). Information is also included from the current NERF investigation with sub-surface chemical data provided for DH 698, 766 and 800.

Samples collected during this investigation were pre-crushed to less than 10 mm and then processed by Coal Research Ltd to provide proximate analysis, sulphur and Specific Energy data.

4.3.3 Results

The chemical data are presented in Table 4.3.

Sample locations are described in detail in Chapter 3.

Values for the samples from New Point Elizabeth Mine required correction. Volatile matter is now measured at a higher temperature, hence values required adjustment to a modern equivalent. CRA have provided the following formula to this end (after Newman 1985).

$$\text{VM\% (New)} = \text{VM\% (Old)} \times 0.914 + 5.577$$

The conversion of volatile matter and specific energy to dry mineral matter and sulphur free (dmmSf) was completed using standard formula for New Zealand coals after Suggate (1995) and Newman, Price & Johnson (1997).

$$\text{Specific Energy (dmmSf)} = \frac{100(\text{Specific Energy} - 0.095\ \text{Sulphur})}{100 - \text{Mineral Matter} - \text{Sulphur}}$$

$$\text{Volatile Matter (dmmSf)} = \frac{100\ (\text{Volatile Matter} - 0.1\ \text{Ash} - 0.5\ \text{Sulphur})}{100 - 1.1\ \text{Ash} - \text{Sulphur}}$$

Where all of the units are expressed on a dry basis.

Table 4.3 Chemical Data

Sample #	Formation	Seam Reference	Moisture	Ash	Volatile M	Specific E	Sulphur	VM (dmmSf)	Specific E (dmmSf)
			As received basis						
CN1	Dunollie	0.--1.0m	10.5	1.1	36.3	27.51	0.41	42.0	31.3
CN2	Dunollie	1.0 -- 2.0m	9.4	0.7	37.9	28.43	0.43	43.0	31.7
CN3	Dunollie	2.0 -- 3.0m	8.6	3.8	36.5	28.05	0.53	42.3	32.3
CN6 /1	Dunollie		5.6	6.2	38.8	27.85	2.11	44.1	32.4
CN6 /2	Dunollie		5.8	3.1	40.2	29.10	0.42	44.5	32.2
CN6 /3	Dunollie		5.7	7.2	38.2	27.30	0.51	44.0	31.7
CN13	Dunollie		5.1	5.4	38.6	28.73	0.43	43.3	32.4
CN22	Dunollie		9.6	5.2	38.2	20.24	0.20	45.6	23.9
Birchfields 4 \ 1	Brunner P	Roof	11.9	4.9	36.5	24.12	0.44	44.8	29.3
Birchfields 4 \ 2	Brunner P	Roof - 1m	12.2	3.3	38.0	25.06	0.46	46.1	29.9
Birchfields 4 \ 3	Brunner P	Mid seam	9.2	3.2	41.5	27.94	0.60	48.2	32.2
Birchfields 4 \ 4	Brunner P	Floor	10.1	15.2	33.7	22.49	0.71	45.4	30.9
Tiller - A	Dunollie		7.8	3.2	37.6	29.35	0.62	42.8	33.3
Tiller - B	Dunollie		7.3	2.0	38.4	30.10	0.57	42.9	33.4
Tiller - C	Dunollie		8.0	2.2	36.9	29.58	0.63	41.7	33.2
Tiller - D	Dunollie		7.8	3.6	36.5	29.17	0.52	41.8	33.2
52/164	Dunollie		6.3	8.6	41.5	28.24	0.87	49.0	33.8
52/165	Dunollie		6.3	2.6	40.0	25.64	0.54	44.4	28.3
52/166	Dunollie		10.8	0.9	36.4	27.07	0.50	42.2	30.8
52/167	Dunollie		12.7	1.1	34.8	26.46	0.47	41.6	30.9
52/168	Dunollie		11.7	6.0	32.9	25.42	0.42	40.8	31.2
52/169	Dunollie		7.2	1.8	40.5	29.00	0.33	45.1	32.0
52/170	Dunollie		8.4	2.4	37.0	29.11	0.45	42.2	32.8
52/171	Dunollie		12.0	2.6	31.6	26.52	0.63	38.0	31.3
52/172	Brunner P		9.1	9.7	39.5	25.89	1.04	49.2	32.6
52/173	Brunner P		9.4	12.2	38.3	24.71	1.26	49.3	32.4
52/174	Brunner P		7.5	5.7	45.7	28.33	1.28	53.2	33.2
52/175	Dunollie		11.2	4.9	36.2	26.51	0.67	44.0	32.0
52/176	Dunollie		12.5	1.2	39.4	27.47	0.38	46.9	32.0
52/177	Dunollie		12.4	2.6	35.2	26.69	0.28	42.5	31.6
52/178	Dunollie		11.7	1.8	36.1	27.20	0.27	42.8	31.6
52/179	Dunollie		11.8	2.8	35.3	27.04	0.25	42.4	31.8
*	Dunollie		7.07	2.93	47.75		1.04	53.7	
*	Dunollie		10.3	3.9	40.4		0.6	48.0	

* This data is from the New Point Elizabeth Mine records. Samples were taken from within the mine in 1930 and 1946

Sample #	Formation	Seam Reference	Moisture	Ash	Volatile M	Specific E	Sulphur	VM (dmmSf)	Specific E (dmmSf)
NERF 1	Brunner P	DH698 48.42-48.65	8.1	10.1	40.1	25.81	1.30	49.4	32.3
NERF 2	Brunner P	DH698 55.39-55.51	8.2	13.6	37.8	24.31	1.21	48.5	32.0
NERF 3	Brunner P	DH698 55.57-55.68	7.5	5.7	45.7	28.33	1.28	53.2	33.2
NERF 4	Brunner P	DH698 55.69-55.73	7.0	10.2	42.1	26.83	1.16	51.1	33.1
NERF 5	Dunollie	DH698 82.31-82.42	10.2	5.9	34.7	25.96	0.55	42.1	31.3
NERF 6	Dunollie	DH698 82.42-82.82	10.4	3.0	35.8	26.37	0.77	42.2	30.7
NERF 7	Dunollie	DH698 82.52-82.60	8.7	4.5	41.9	27.54	0.54	49.0	32.0
NERF 8	Dunollie	DH698 97.60-97.90	11.2	1.8	37.6	27.14	0.36	44.2	31.4
NERF 9	Dunollie	DH698 97.90-98.10	11.6	1.0	34.6	27.08	0.28	40.7	31.1
NERF 10	Dunollie	DH698 98.10-98.31	11.5	2.3	34.9	26.65	0.28	41.5	31.1
NERF 11	Dunollie	DH698 99.20-99.43	10.9	1.9	35.5	27.05	0.26	41.7	31.2
NERF 12	Dunollie	DH698 99.43-99.64	9.8	2.6	36.5	27.30	0.26	42.5	31.3
NERF 13	Dunollie	DH698 99.64-99.76	11.3	1.8	35.1	26.96	0.23	41.4	31.1
NERF 14	Dunollie	DH698 99.76-99.90	11.6	2.4	33.6	26.64	0.23	40.1	31.1
NERF 15	Dunollie	DH698 99.90-100.0	10.3	2.4	34.2	27.55	0.24	40.1	31.7
NERF 16	Brunner P	DH766 116.24-	6.9	4.3	47.7	29.56	1.46	54.3	33.9
NERF 17	Brunner P	DH766 116.40-	4.7	1.8	53.2	30.78	1.47	57.4	33.4
NERF 18	Brunner P	DH766 116.56-	5.0	7.9	50.8	29.20	3.84	58.9	35.0
NERF 19	Brunner P	DH766 116.66-	8.8	7.3	39.9	26.76	1.64	48.1	32.6
NERF 20	Brunner P	DH766 116.76-	9.3	12.1	35.6	24.12	3.47	45.5	32.2
NERF 21	Dunollie	DH766 158.17-	13.1	3.1	33.3	26.18	0.46	40.9	31.5
NERF 22	Dunollie	DH766 158.41-	12.4	3.4	37.0	26.67	0.55	45.0	32.0
NERF 23	Dunollie	DH766 158.69-	10.9	16.2	31.5	22.76	0.43	43.5	32.1
NERF 24	Dunollie	DH766 158.88-	12.0	3.8	37.5	26.96	0.56	45.6	32.3
NERF 25	Dunollie	DH766 159.28-	11.8	11.3	33.4	24.30	0.75	44.1	32.3
NERF 26	Dunollie	DH766 159.90-	13.0	3.7	35.0	26.36	0.47	43.1	31.9
NERF 27	Dunollie	DH766 160.10-	13.9	2.5	33.2	26.23	0.36	41.0	31.6
NERF 28	Dunollie	DH766 160.28-	12.6	3.1	36.4	26.92	0.26	44.3	32.1
NERF 29	Dunollie	DH766 212.45-	13.9	0.9	32.3	26.71	0.26	39.2	31.4
NERF 30	Dunollie	DH766 213.05-	13.9	0.9	32.6	26.68	0.23	39.6	31.4
NERF 31	Dunollie	DH766 213.66-	12.3	9.5	30.9	24.68	0.22	40.3	32.0
NERF 32	Dunollie	DH766 227.15-	11.7	4.2	36.1	27.12	0.35	43.9	32.5
NERF 33	Brunner P	DH800 62.80-63.00	5.8	14.6	39.8	25.30	0.94	49.9	32.7
NERF 34	Brunner P	DH800 63.00-63.28	6.8	8.1	44.7	27.84	1.01	52.9	33.3
NERF 35	Brunner P	DH800 63.28-63.52	6.2	16.8	40.2	24.70	1.36	52.1	33.2
NERF 36	Brunner P	DH800 63.52-63.68	9.2	6.8	39.3	26.94	1.06	47.4	32.6
NERF 37	Brunner P	DH800 63.68-63.94	10.7	6.1	35.3	26.00	0.90	43.2	31.7
NERF 38	Brunner P	DH800 63.94-64.10	10.6	11.3	34.1	24.12	0.92	44.2	31.6
NERF 39	Brunner P	DH800 63.22-64.36	8.4	12.0	37.1	24.92	1.30	46.8	32.2

The chemical analyses for some samples must be treated with caution. For example, weathering has altered samples CN22 and 52/165. The effect of this weathering is most noticeable affecting Specific Energy. For example sample CN22 was extracted from a relatively thick seam correlated to the New Point Elizabeth Seam. However, at the sampling location the dip of the seam was parallel to the ground surface with the seam lying approximately 20 cm. below ground. In an attempt was made to freshen the outcrop ~1.5 – 2 metres of material was excavated from the face before sampling. Both petrographic and chemical investigations indicate that despite these measures the sample obtained was still significantly weathered. This weathering produced visible effects in the polished blocks (Figure 4.6).

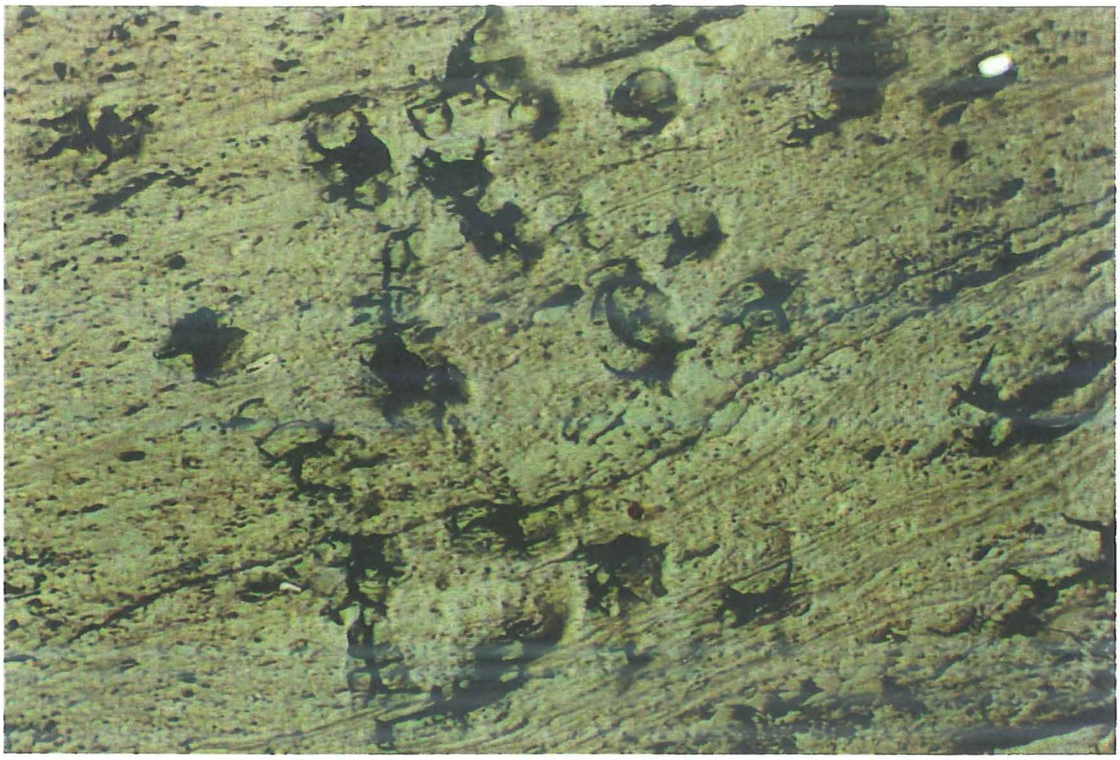


Figure 4.6: Polished sample of weathered coal

4.3.4 Discussion

There is a noticeable differentiation between Brunner P and Dunollie seams. However, within each group of seams, i.e. Dunollie and Brunner P respectively, coal chemistry remains relatively consistent.

The Suggate plot (figure 4.7) illustrates the distinction between Dunollie and Brunner coals. Dunollie coals are mainly clumped around the average type line and towards the upper part of the sub-bituminous range. The samples from Tiller mine are displaced from the other Dunollie samples, as the Tiller seam occurs at the very base of the Dunollie succession and nearer to the basin axis, and is consequently of higher rank than the upper Dunollie coals sampled in DH698, DH766 and in outcrop. The Brunner P samples are spread along a line, indicating variable type but similar rank. Samples from Birchfields Opencast occur on or close to the average type line while Brunner P samples from the thinner seams show greater variability in volatile matter.

Volatile matter of vitrinite rich coals has been used as an indicator of peat oxygenation, as variations are strongly influenced by oxygen access, which is controlled by peat drainage during deposition (Newman & Newman 1982, Johnson 1987). Poorly oxygenated peat results in a relative enrichment of hydrogen content, resulting in coals with elevated volatile matter. Well drained and oxygenated peat produces coals with 'normal' volatile matter. These coals lie near the average type line of a Suggate plot.

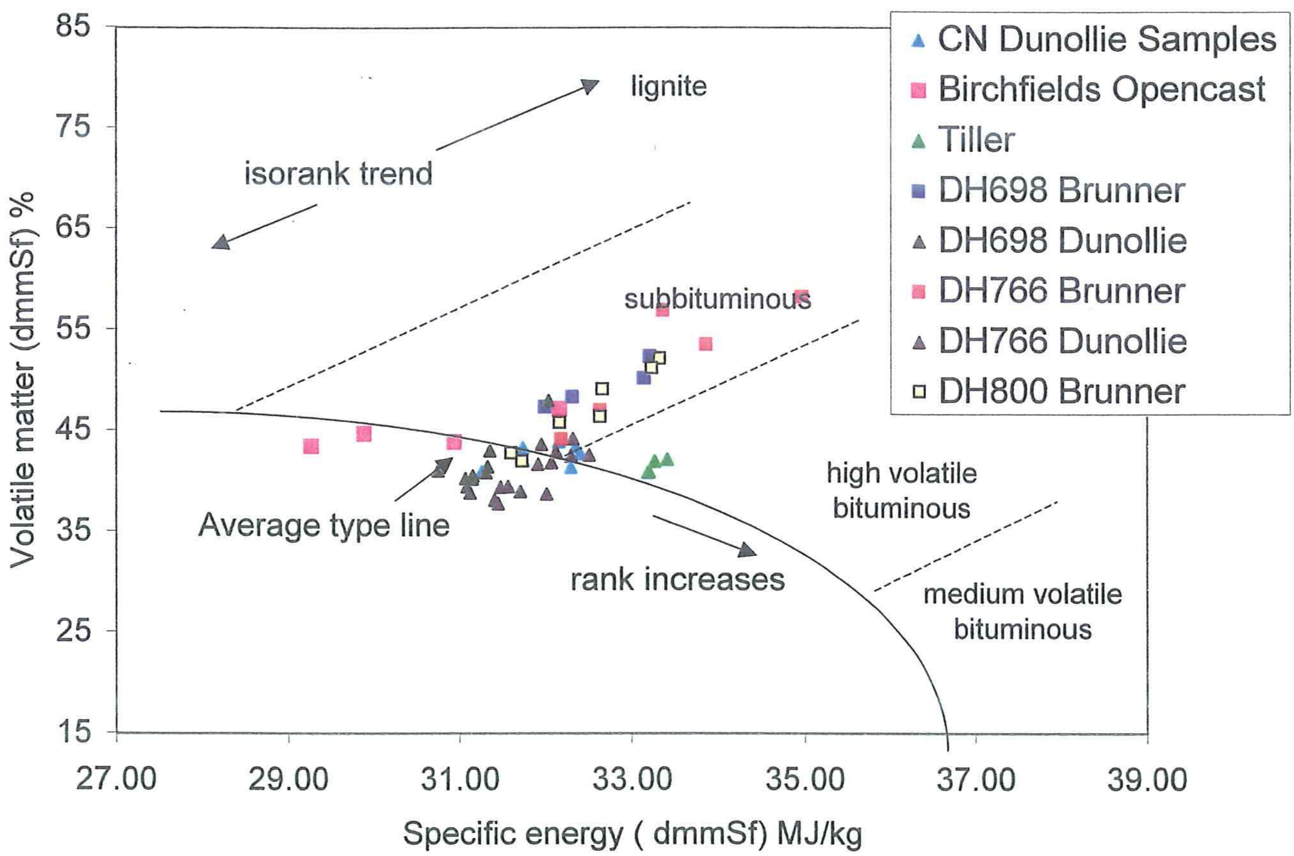


Figure 4.7 Modified Suggate plot, after Suggate 1959, and Newman, Price and Johnston 1997. The position of the average type line, which represents the hypothetical coalification path of a coal of average type is only approximate. The isorank lines accommodate chemical variability resulting from type differences between coals of equal rank. The positions of the rank boundaries are approximate.

Coals from the Brunner P and Dunollie groups can generally be distinguished on the basis of volatile matter (dmmSf) and sulphur content. Most Brunner P coals have volatile matter ranging from 47% up to 55%, and their sulphur content ranges from 0.9% to 3.84%, with an average of ~1.3%. Dunollie coals have lower volatile matter and sulphur contents. Volatile matter typically ranges from 38% to 45% while sulphur ranges from 0.2% to 2.11% with an average of ~0.6%.

The higher sulphur content of Brunner P seams relative to Dunollie seams is due to the proximity of Brunner P to the overlying Island Sandstone. Marine fluids permeated into the Brunner sediments during deposition of the Island Sandstone, introducing sulphur into the shallowly buried peats. Suggate (1959) and Newman (1991) cite the influence of circulating marine groundwater as a mechanism for elevating sulphur levels within coals that otherwise would have had very low sulphur contents (Querol et al 1991).

The samples from Birchfields Opencast Mine provide an exception to the general Brunner P case, with relatively low average volatile matter (46.1%) and sulphur (0.55%). The low sulphur content is attributed to the presence of a 'rider' seam overlying the main seam. This thin peat body sheltered the main seam by trapping the sulphur present in percolating marine waters. The samples from Birchfields Opencast also have relatively low volatile matter, compared to the other Brunner P coals sampled. While coal is common within the Brunner P at Greymouth, thick seams are rare and Birchfields Seam represents the only sustained mire development within the Brunner P. Hence, the Birchfields Seam may have had a different mire flora than was present in the relatively short-lived mires that occurred elsewhere in the Brunner P. Persistence of mire conditions may indicate that the mire was raised. A rain fed raised mire profile allows accumulation of thick clean peat isolated from fluvial activity. This set of growing conditions unusual for the Brunner P., and may be responsible for both the low TPI values and low volatile matter compared to other Brunner P coals (Grady et al. 1993).

Volatile matter can be elevated by early introduction of sulphur in groundwater as occurred in the case of Pike River coals (Newman 1991). However, the NERF

Brunner P samples show no relationship between sulphur content and volatile matter (pers comm. J. Newman.) Which suggests that sulphur access to Brunner P peats was delayed for a significant time after deposition (Newman 1991).

More work on the Birchfields seam would be required to test these conclusions. Work would ideally include chemical sampling at a higher resolution in association with detailed palynology, in order to determine whether floral assemblage changed during the development of the Birchfields seam, and whether this floral assemblage indicates the development of a specific style of mire. Unfortunately, only small and incomplete remnants of this seam have survived mining in the 1980's, and suitable samples cannot be obtained.

Sample CN6/1 is another anomaly. It was collected from the first Dunollie seam below the Birchfields seam. This seam occurs approximately 25m below the base of the Birchfields seam under the Brunner Conglomerate Member. While the overlying Birchfields seam is low in sulphur as detailed above, CN6/1 has the highest sulphur percentage of all the Dunollie samples (2.11%). Brunner conglomerates at this location dominate the material between the Dunollie and the Island Sandstone, and only a thin Brunner P is present. It is therefore likely that during deposition of the Island Sandstone the Brunner Conglomerate Member allowed marine waters to penetrate to the top of the Dunollie. Volatile matter is close to the Dunollie normal for this sample which supports the concept that sulphur access was delayed (Newman 1991). To the south-east the Brunner Conglomerate Member contains a greater proportion of fine material, which will have reduced the penetration of marine fluids from above, protecting the New Point Elizabeth seam from sulphur enrichment.

Volatile matter remains consistent thorough the NPE seam, ranging from 42.0% to 43.0%. Therefore there is not a close relationship between TPI and volatile matter. The distribution of the PM3 field in figure 4.3 endorses this. The change in mire flora from angiosperm abundant to angiosperm poor up seam indicates that volatile matter was also not strongly related to the floral community.

4.4 Palynology

4.4.1 Introduction

Palynology, which has been discussed in Chapter 2 in the context of biostratigraphic dating, can also provide insight into paleomire environment. Palynology provides direct evidence of the floral assemblage occurring within and around paleomires. Palynology can also identify changes in mire flora, which may suggest changes in climatic conditions and the development of more competitive species. However, when coal seams are thin or discontinuous, their flora may resemble the local floodplain vegetation rather than the specialised flora associated thick peat accumulations (Ward 1997). Previous work suggests that most pollen falls close to the parent plant with only limited transport of pollen occurring within the basin (Moore 1996, Ward 1997, and Hayes 1999). The palynological assemblages even of thin seams are therefore believed to be representative of the flora from which the peat was derived, with relatively minor contamination be flora that did not contribute to the peat.

Commencing in the late Cretaceous the relative abundance of angiosperms and gymnosperms changes. Angiosperm pollen is relatively uncommon in Cretaceous coals, but becomes more common in the Paleocene. This shift is due to evolutionary change allowing angiosperms to compete more effectively in the previously gymnosperm dominated mire environment (Moore 1996). The later Paleocene was also a period of warm climatic conditions and angiosperms perform better than gymnosperms under warm conditions. During the Paleocene, mean annual temperate increased from 14°C at the end of the Cretaceous (Kennedy 1993) to 23°C by the Eocene based on physiognomic analysis of fossil megaflora (Newman et al 1993).

4.4.2 Method

The information used in this section was gathered as part of a FRST programme (CRA 802). The "NERF" samples collected for the FRST investigation were analysed by N. Moore of CRL Energy Research and Testing. After an initial review of the NERF palynology data, eight samples from the present thesis study were prepared for analysis by N. Moore.

4.4.3 Results

Palynological results from the NERF analyses are provided in Table 4.4.

Samples are from drillholes 698, 766 and 800. Drillhole locations are provided in figure 3.1 (Chapter 3 pg. 41). Samples 2 and 4 from DH 698 are Brunner P, while samples 5 – 15 are from three Dunollie seams. From DH 766 samples 16 – 20 are Brunner P and 21 – 30 are Dunollie. Within DH 800 all of the material sampled is Brunner P comprising samples 33-39. Data for samples 1 and 3 were not provided in the NERF analyses received.

Results from the additional samples are presented in Table 4.5. Samples CN 23 – 26 are from the New Point Elizabeth seam, and correspond to the chemical samples CN1-3 and the CN1 series from the petrology. Samples BF 4/1 – 4/4 are from the Birchfields Seam and are splits of the same material as sampled for chemical analysis and petrology.

	Nerf 2	Nerf 4	Nerf 5	Nerf 6	Nerf 7	Nerf 8	Nerf 9	Nerf 10	Nerf 11	Nerf 12	Nerf 13	Nerf 14	Nerf 15	Nerf 16	Nerf 17	Nerf 18	Nerf 19	Nerf 20	Nerf 21	Nerf 22	Nerf 23	Nerf 24	Nerf 25	Nerf 26	Nerf 27	Nerf 28	Nerf 29	Nerf 30	Nerf 33	Nerf 34	Nerf 35	Nerf 36	Nerf 37	Nerf 38	Nerf 39
Drillhole	689	689	689	689	689	689	689	689	689	689	689	689	689	766	766	766	766	766	766	766	766	766	766	766	766	766	766	766	800	800	800	800	800	800	800
Formation Sampled	B	B	D	D	D	D	D	D	D	D	D	D	D	B	B	B	B	B	D	D	D	D	D	D	D	D	D	D	B	B	B	B	B	B	B
Triorites minor	5		32	9	23	76	29	35	104	125	84	29	38	5	13	7	87	150	1	75	147	35	21	106	17	70	8	10	12	1	1	27	25	78	3
Triorites fragilis																						3													
Triorites granularis										1				3	1		1			1	4	1			1										
Triorites spherical, small	1																												1						
Haloragicites harissii	6	12	20		1				1	5	2	1	1	63	64	47	10	3		6	3	5	9	5					3	12	7	16	9	11	2
Proteacidites scabratus		4	2		1	2	3	6	7	6	6	37	3	24	17	8	23	16	2	10	1		3	2	7	1	2		12	20	14	10	5	9	8
Proteacidites annularis										1	1		1	17	52	39	4				1	1	1	1	1				1	10	8	11	6	1	16
Proteacidites crassus														3		5														1					
Tricolpites reticulatus				1			1	7		1		3				1		4	1		1	2			1	1		1							1
Tricolpites secarius		3	1	1		1	1	2	6	2	1	1		2	1		4	4		2		1		2	1						2		12	6	
Tricolpites. AA	109	100	19	5	8	18	5	3	9	9	2	4	6	25	10	23	15	17	4	12	7	9	3	10	1	4	4	12	8	4	5	6	5	8	6
Tricolpites CC	4	9					4	6				8					1	1	1		1						1			2	6	7	5	7	4
Tricolpites Y							1		1	2	2		3																						
Trivolpites lillei																					2		1						4		1	1		2	
Tricolpites ricegrainus	17	27	1		2	2	12		1	2			2	1		3	6	9	1	6	1	7	1	1	2	3	3	5	2	3	3	2	3	4	5
Nothofagus					1	1	1	3				5								1						1				1		2		1	
Liliacidites sp.		6		1			9	14	6	5	2		6	21		10	3	2	1	2	1	1	2			3	4		1				2	1	1
Myrtaceidites parvus	82	1					3	1													2	2						2	1			6	19	2	
Myrtaceidites parvus (big)	2																																		
Monocolpites sp.	6	1		1		2			1		3	1	6			1			1		1	1					1	2	2						
Monocolporites sp.	1								3	3			1			3						1													
Rhoipites sp.	1	1				1	1		1											2	1	3				1	3	1	1				2		
Malvacipollis subtilis	15	16	2				1							10	3	2	2	2		1		1													
Monosulcites promenatus	3	6												2			1										1	1							
Small, even spines																					1														
Tricolporites sp.	35	8	1	1	1	1			1				2	1		1	5			4	1		1			2	1	9	1	3	1	4	13	4	1
Anisotricolporites truncatus			1																																
Lymingtonia cenozoica	1	2	8	2	2	4			5	5	2		3	3	2	4	1			1	2	2	2	4			3	13				6	3	1	5
Palmidites maximus?		3																																	
Camelia										2												1	1				1		2						
Striated	3																																		
Total Angiosperms	288	199	87	21	39	108	71	77	146	169	105	89	72	180	163	154	163	208	12	123	177	76	45	131	31	86	32	56	51	57	48	98	109	135	105
Trichotomosulcites sp.	1		1	1		4			5	7	2		5			3	1				2	2	1	1			2		1	2	4	1			
Podocarpidites sp.	3		8	3	1	5	1	1	4	1		9	5	2	1	6	4	2	4	5	4	1	8	1	3	4	9	9		6	6	3	4	3	3
Phyllocladidites mawsonii	11	6	103	161	191	130	176	123	121	79	131	98	153	64	82	88	143	32	220	142	100	160	179	133	197	146	140	125	143	145	173	136	136	136	145
Microcacryidites antarcticus		1	2			1	5	3	1	1	1	4	1		2	4	2	1	1	1	1	1	2		1	5	6			2	14	1			
Araucariacites sp.				1		1			2	1							5	1	1	3	4	2	2				9								
Total Gymnosperms	15	7	114	166	192	141	182	127	133	89	134	111	164	66	85	101	155	36	226	151	111	166	192	135	201	155	166	134	144	155	197	141	140	139	148
Laevigatosporites ovatus	16	10	27	15	8	5	1	2	7	12	5	7	12	13	11	17	8	9	6	4	1	3	8	9	1	5	17	10	9	6	3	4	7	12	7
Peromonolites bowenii		1	10	2	2	4			9	7	8	4	9	2	4	4	3	2		1		3		3		1	29	7	5	3		6	5	5	2
Cyathidites minor	1	1			1		3	1	1	2		1							1		1	2	2			1	2	9	1						
Gleichenia sp.	3	3	13	61	10		9	1	6	5	17	2	3	1					66	11	2	13	1	2	1	2	60	32	2		1	1			
Clavifera triplex																			1	3															
Clavifera rudis																		1	4	1		8													
Triletes verrucatus				2	2	2						2			1		1	1	2	1		3				4	13	9							
T. tuberculiformis				1																															
T. granularis												3																1							
T. morleyi																						1													
T. morleyi (small)						1					2					4		1				2	2												
Lycopodia			2	1		3			3	3	9		2					3	3	2	1			1			3	1	1	1		1		3	2
Monoletes coffeebeanus																										1									
Monoletes smooth											1						2										5								
Monoletes cauliflower																											4								
Stereisporites antiquasporites	3		1																																
Spherical, pillow-texture	1																																	1	
Smooth, long-lipped																	3			3		1	1												
Smooth, long																						2	2												
"Fuzzball" - indistinct									1	3	1		5	15									1	5						5	3			2	
Picture #11																											1	1							
Total Spores	24	15	53	82	23	15	13	4	27	32	43	19	31	31	16	25	17	17	83	26	5	38	17	20	2	14	134	70	18	15	7	12	12	23	11
Total Palynomorphs	327	221	254	269	254	264	266	208	306	290	282	219	267	277	264	280	335	261	321	300	293	280	254	286	234	255	332	260	213	227	252	251	261	297	264

Table 4.4 Palynology Results for the NERF data set
From Moore 1999.

Formation Sampled B = Brunner P D = Dunollie

Sample Number	CN 0.9 - 1.1	CN 1.3 - 1.5	CN 1.7 - 2.1	CN 2.4 - 2.9	BF 4/1	BF 4/2	BF 4/3	BF 4/4
Formation Sampled	Dunollie	Dunollie	Dunollie	Dunollie	B-P	B-P	B-P	B-P
Triorites minor	34	35	12	141	57	37	22	33
Triorites fragilis	1				7	7	9	7
Triorites granularis						2	1	
Triorites spherical, small						1		
Haloragicites harissii					6	11	15	7
Proteacidites scabratus			1	1		3	19	21
Proteacidites annularis						9	36	15
Proteacidites crassus						8	5	2
Proteacidites palisadus			2				1	
Proteacidites retiformis							1	1
Proteacidites stratosus								1
Tricolpites secarius					1			
Tricolpites pachyexinus					1			
Tricolpites. AA	10	4	11	31	6	7	6	22
Tricolpites CC							1	1
Tricolpites (small)						1		
Tricolpites lillei	1		1	6	1			13
Tricolpites ricegrainus			1				2	2
Liliacidites sp.							1	
Myrtaceidites parvus				1				
Monocolpites sp.					1			
Monocolporites sp.								
Rhoipites aveolatus					2			
Rhoipites sp.					2	4		
Monosulcites promenatus		1		1				
Tricolporites sp.		1	1		1		2	1
Lymingtonia cenozoica				3	3	3		
Palmidites maximus?						1		
Plagianthus?					1			
Striated							1	
Total Angiosperms	46	41	29	184	89	94	122	126
Trichotomosulcites sp.		2	3	4	1	5	2	2
Podocarpidites sp.	9	4	11	22	7	24	40	17
Phyllocladidites mawsonii	213	211	250	84	154	118	95	105
Microcacryidites antarcticus	2	1	1	3	3	8	3	1
Total Gymnosperms	224	218	265	113	165	155	140	125
Laevigatosporites ovatus					1			
Peromonolites bowenii	4	2	5	6		6	7	3
Cyathidites sp.	4			2	1			1
Gleichenia sp.	2			1				
Triletes verrucatus				4	1	2		2
T. morleyi	1			2	1	1		
T. fragilis	1							
T. morleyi (small)								2
Trilete, bacculate						1		
Lycopodia	2	2	6	1				
Monoletes smooth				1	2	1	2	2
Smooth, long-lipped							1	1
"Fuzzball" - indistinct					1			
Tetrad								1
Total Spores	14	4	11	17	7	11	10	12
Total Palynomorphs	284	263	305	314	261	260	272	263

Table 4.5 Additonal Palynology Results

4.4.4 Discussion

There are two important indicators within the palynology results. These are the ratio of angiosperms to gymnosperms, and the occurrence and abundance of Gleichenia spores.

Gleicheniaceae is a family of primitive ferns, found throughout Australasia (Ward et al 1995). Modern Gleichenia closely resembles preserved fossil mega-floral material and is found in mires and wetlands. Modern spores also closely resemble specimens from the rock record and fossil Gleichenia is thought to have preferred similar environments to the modern form (Kennedy 1993, Ward 1995). Gleichenia colonisation of paleomires is thought to represent dryer or better-drained conditions than those preferred by the majority of late Cretaceous – early Tertiary mire flora (Ward 1995, Moore 1996). Gleichenia is particularly tolerant of fire, allowing for quick regeneration and temporary dominance of the mire flora following burning. Moore (1996) suggests that the replacement of the canopy flora with Gleichenia following a burn off within the mire may result in increased evaporation from the mire leading to a dryer peat and a greater susceptibility to future fires, preventing the regeneration of earlier flora assemblages. Within the NERF data set a spike in Gleichenia occurrence is seen in the uppermost Dunollie seam for each drillhole sampled (figure 4.8). Given that Gleichenia is believed to have deposited its spores within 100 meters of the parent plant (Moore 1996) the change responsible for the increase in Gleichenia spores must have occurred throughout the study area.

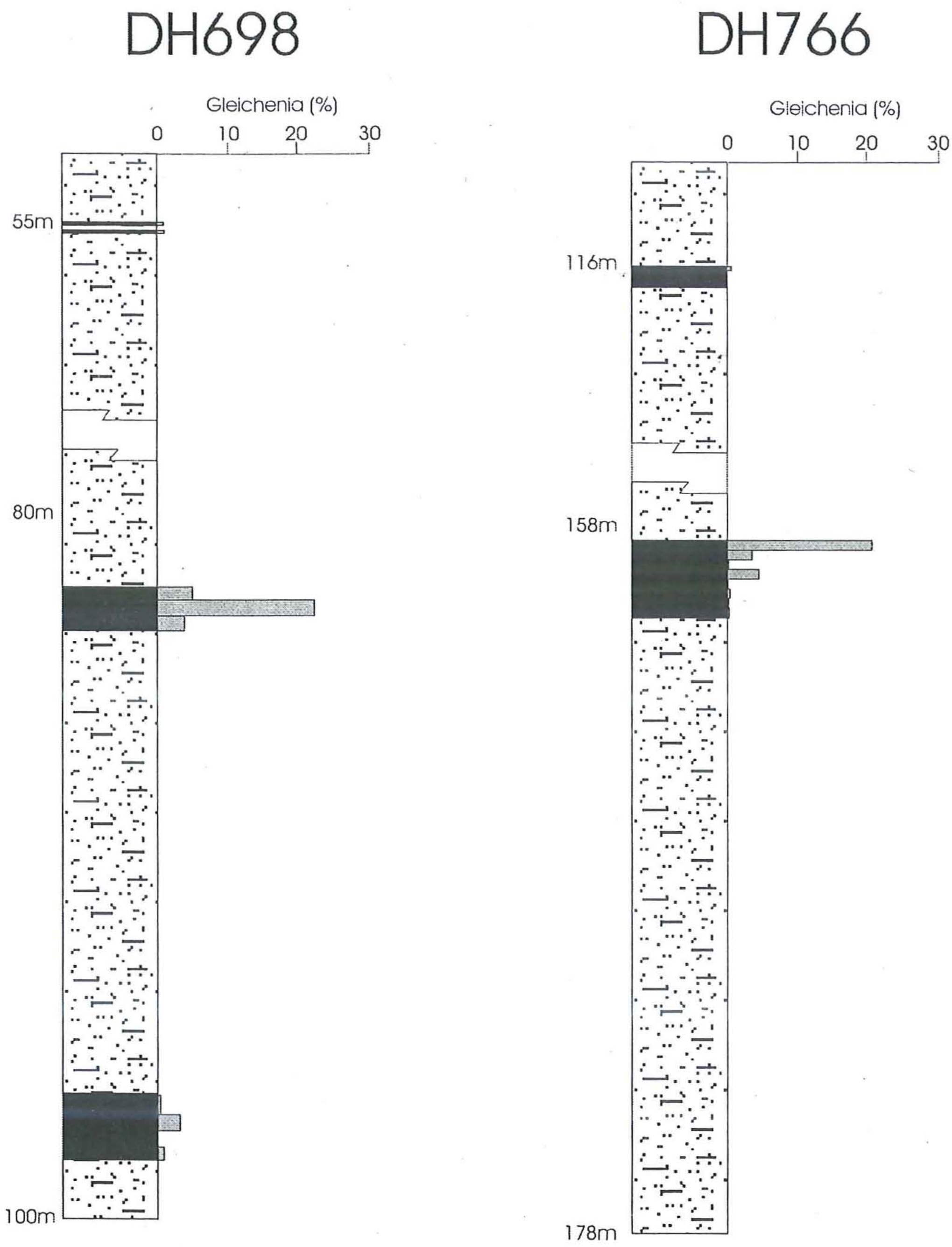


Figure 4.8 Percentage of Gleichenia within Brunner P and upper Dunollie seams.

Moore (1996) also identified a widespread synchronised change from P. mawsonii dominance to Gleichenia dominance in an Upper Rewanui seam near the end of the Cretaceous, and attributed this change to altered climatic conditions (Moore 1996, 1996a). The development of an extensive drainage system within the mire could also have resulted in dryer conditions allowing Gleichenia to become established. The peak in occurrence of Gleichenia at the end of Dunollie mire development is considered likely to indicate a combination of climatic change in the lower Paleocene and the development of the drainage drawing water out of the mire. Drier mire conditions would result in a greater potential for fires, the resulting destabilisation of the mire would have allowed hardier 'opportunist' species such as Gleichenia to spread within the mire.

Results from the Dunollie seam included in the additional palynology set (Table 4.5) did not show a peak in Gleichenia towards the top of the seam. However, the sampling resolution (~1m plies) was not fine enough to allow for its detection, even if it were present. The plies with high Gleichenia in DH698 and DH766 are ~20 cm thick.

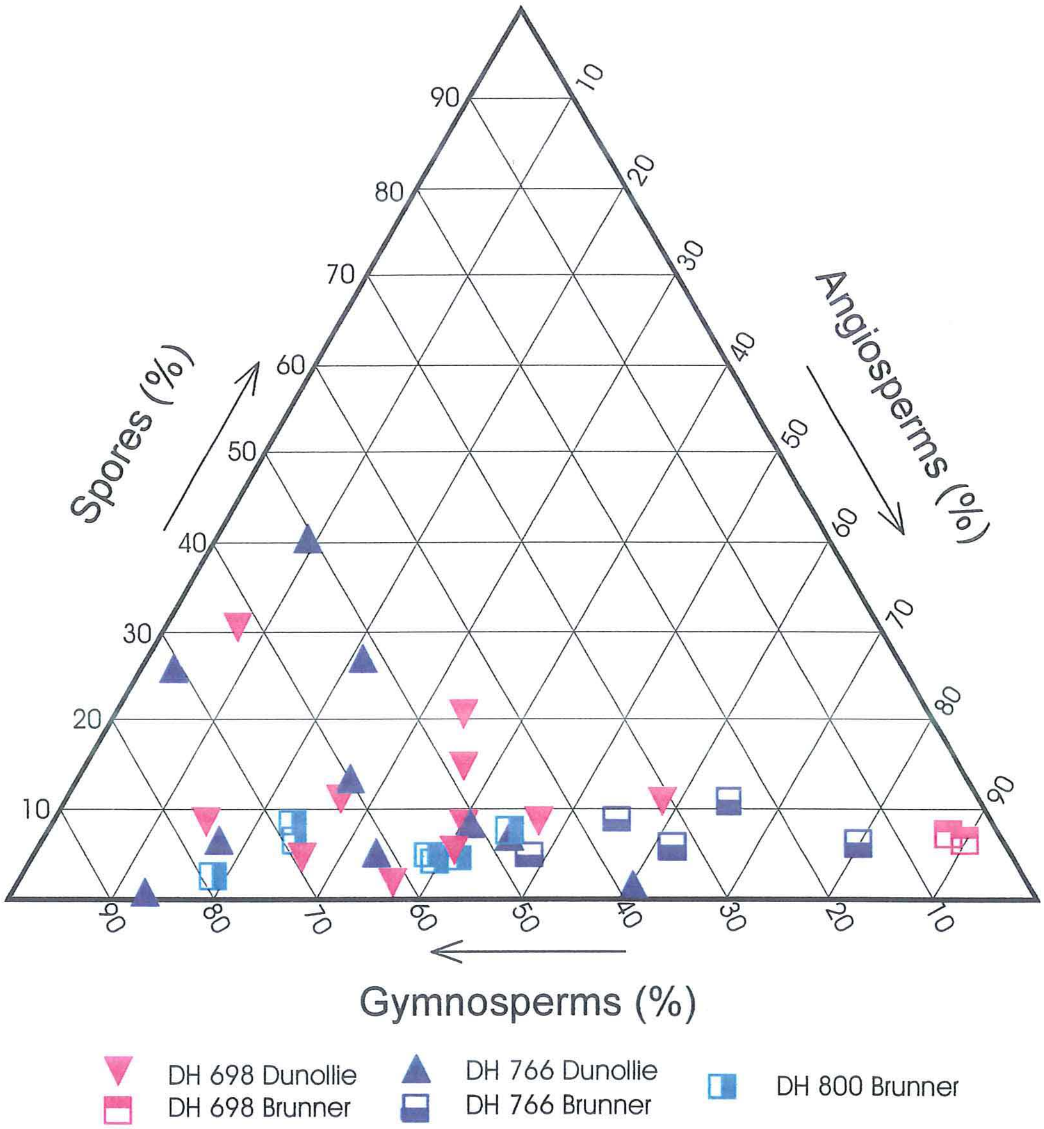


Figure 4.9 Relative abundance of angiosperms, gymnosperms and spores

Figure 4.9 indicates that the Brunner P generally has higher angiosperm abundance than Dunollie samples from the same drillhole. This change in the balance of mire flora between Dunollie and Brunner P deposition can be at least partially explained in terms of the Tertiary evolutionary development and radiation of the angiosperms. Another possible reason for increased angiosperms is warmer climatic conditions.

Work on the NERF data has shown a link between angiosperm abundance and the occurrence of isotopically light carbon $\delta^{13}C$ (pers. comm. Newman 2000). During the late Paleocene thermal maximum there is increase in the atmospheric occurrence of isotopically depleted carbon (Zachos 1999). The warming and the increase in the occurrence of $\delta^{13}C$ have been attributed to the introduction of large volumes of methane into the atmosphere, producing a 'greenhouse' effect (Dickens et al 1997, Thiel et al 1999). The fluctuation of $\delta^{13}C$ and angiosperm abundance within Greymouth Coalfield can be indicated from previous analysis of the FRST data. The Australian Geological Survey Organisation (AGSO) analysed samples for $\delta^{13}C$ (Boreham et al 1998). The same samples also had relative pollen abundance completed as part of a separate investigation (Newman et al 1999). This data if presented below in table 4.6.

					Palynology		
Sample ID	Drillhole	Age	Formation	$\delta^{13}C$	Angiosperms	Gymnosperms	Pteridophytes
				‰			
52/172	DH698	Paleocene	Brunner P	-26.62	68.2	29.0	2.8
52/174	DH698	Paleocene	Brunner P	-31.27	81.4	5.5	13.1
52/178	DH698	Paleocene	Dunollie	-27.51	38.8	48.3	12.9
26/376	DH628	Latest Cret.	Rewanui	-27.04	4.3	74.0	21.7
26/662	DH628	Latest Cret.	Rewanui	-26.74	8.4	78.2	13.4

Table 4.6: $\delta^{13}C$ and Palynology abundance.

After Boreham et al 1998 and Newman et al 1999.

Samples 26/376 and 26/662 represent average or normal conditions within the Late Cretaceous. $\delta^{13}C$ has a value of approximately -27.0, and gymnosperms dominate over angiosperms. The Paleocene lower Dunollie sample 52/178 shows a normal $\delta^{13}C$ though an increase in the relative abundance of angiosperms. Sample 52/174 in the lower Brunner P has an anomalous $\delta^{13}C$ value, which corresponds with highest abundance of angiosperm pollen. Overlying sample 52/172 in the upper Brunner P shows $\delta^{13}C$ returning to 'normal' while the relative abundance of angiosperms decreases, although they still remain more abundant than gymnosperms.

The relative increase in angiosperms to gymnosperms within the Paleocene appears to be due to a combination of evolutionary change and climatic conditions. The abundance of angiosperms increases moderately from Late Cretaceous values during the lower Paleocene deposition of the Dunollie Formation. During this time indicators suggest that average temperature was similar to that in the Late Cretaceous, which supports the conclusion that the initial increase in angiosperm abundance was due to evolutionary advances which allowed the angiosperms to compete more effectively with the established gymnosperms. During the late Paleocene, and deposition of the Brunner P, an anomaly in the occurrence of carbon isotopes corresponds to a period of global warming, known as the latest Paleocene thermal maximum. The DH698 data shows that during this warm period the abundance of angiosperms was far greater than gymnosperms. This provided convincing evidence that climate as well as evolutionary trends control angiosperm abundance.

Subsequent work has confirmed the trends between $\delta^{13}C$ and angiosperm occurrence within the Paleocene (pers comm. J. Newman 2000), however the data this subsequent work is based upon is currently part of a proprietary data set.

4.5 Synthesis

Dunollie Formation and Brunner P coal seams can be distinguished using a number of coal properties and any such division should be made using as many properties for reference as possible.

Table 4.7 provides a comparison between the two groups of coal seams.

Coal Property	Dunollie Coals	Brunner P Coals
TPI	Generally low ~0.7 Especially within thin seams	Moderate to high ~2.5
Sulphur Content	Low, average 0.6%	Moderate, average 1.6%
Volatile Matter	38 – 45 %	47 - 55 %
Angiosperm vs. gymnosperm	Angiosperms moderate to rare while gymnosperms dominate	Angiosperms more abundant than gymnosperms
	Angiosperms comprise ~5 – 65% of palynomorphs sampled Average ~35%	Angiosperms comprise ~20 – 95% of palynomorphs sampled Average ~55%
Spore occurrence	Upper Dunollie seams often high in Gleichenia spores towards the roof	Low occurrence of spores, no abundant species

Table 4.7 Comparative summary of coal properties

Coals from the Dunollie Formation are generally vitrinite dominated and low in sulphur and ash. Petrologic variation within the Dunollie coals largely occurs due to changes in the abundance of the liptodetrinite and resinite. Most Dunollie seams are thin, seldom exceeding 30cm thickness and laterally discontinuous. Peat accumulation was sheltered from the fluvial system for relatively limited periods of time, by development of levees containing the meandering or anastomosing fluvial system allowing for the accumulation of clean peat. However, due to the poor development of the levees, the low angle of the flood plane and the relatively low paleotopography, frequent flooding events interrupted or terminated peat accumulation.

It is proposed that most Dunollie peat accumulation occurred within 'sag' ponds or abandoned fluvial channels that had become isolated from the active drainage system. The floral assemblage associated with this environment may have been more closely related to the flood plain flora than the flora present within a well-developed mire. As suggested in Chapter 3 a residual Goldlight Lake to the south may have persisted throughout most of Dunollie deposition. The lake may have maintained a high base level in this southeast part of the basin, assisting mire development, allowing for the accumulation of peat with relatively little input of water by channels directly into the mire. As observed above, the peat in these small mires was subjected to frequent flood events. Overbank spilling and channel avulsion were common caused of flooding events, with a high base level and the low gradient. Early in the deposition of the Dunollie fluctuations in the level of a residual Goldlight Lake may have resulted in inundation of the flood plain, wide spread deposition of fine material and termination of peat accumulation.

The uppermost Dunollie seam is an exception from these 'normal' depositional conditions. In the southeast of the study area the upper seam or New Point Elizabeth (NPE) seam is exceptionally thick for a coal seam within the Dunollie. It also has a distinct set of chemical, petrologic and palynological properties, including a marked spike in the occurrence of Gleichenia towards the roof of the seam. This Gleichenia spike may indicate drying of the mire environment associated with either climatic warming during the Paleocene, or the development of extensive drainage from the mire resulting in lowered water levels and dryer peat.

Resinite, especially the maceral fluorinite, forms layers within the lower portions of the seam often in association with mineral matter, this material was probably deposited during flood events. The flooding may have been due either to overbank spilling of the fluvial system, or brief rises in the regional water. The resinite layering is absent from the mid – upper seam indicating that once mire conditions became well established the thickening peat body was either isolated from, or raised above flooding events.

The NPE seam also had tissue preservation indices that fluctuate vertically within the seam. The significance of these variations in the seams petrologic parameters when compared to other Dunollie seams is uncertain as they are directly or indirectly linked to the seam thickness, and none of the other Dunollie seams have a comparable thickness.

The unusual thickness of the NPE seam relates to the fluvial and tectonic setting at the end of Dunollie deposition. As discussed in Chapter 3 the upper Dunollie Formation was deposited within a meandering fluvial system whereas the lower Dunollie was deposited within an anastomosing fluvial system. As the meander system developed the concentration of fines and organic matter into resistive plugs may have acted to confine fluvial systems away from the southeast of the study area. Establishment of the NPE mire under these more stable conditions will have acted to confine the small fluvial channels associated with the mire, allowing for the accumulation of clean peat while still providing moisture to the mire. Tectonic controls both within and outside the basin may have been waning at this point, hence sedimentation will have slowed as both accommodation within the basin and sediment supply decreased. Stable, possibly raised mire conditions, allowed for the accumulation of cleaner peat, at the same time increasing the effects of oxidation and microbial attack resulting in lower tissue preservation.

Brunner P coals have relatively higher volatile matter than coals from the Dunollie Formation as illustrated in figure 4.7. Brunner P coals also have generally better tissue preservation. It is suggested that Brunner P mires were more anoxic with greater isolation from fluvial activity than Dunollie peat. The anoxic conditions aided the preservation of tissue structures by limiting microbial activity. The anoxic conditions also allowed for relative enrichment in hydrogen content resulting in more volatile matter. The increased abundance of angiosperm material in Brunner P coals may have also affected the volatile mater of the coals. Newman J. has attributed angiosperms with contributing more hydrogen rich vitrinite than gymnosperms.

Birchfields seam is the thickest occurrence of Brunner P coal within the study area. Birchfields seam is unusual, as both TPI and volatile matter are relatively low for Brunner P coals. The sustained mire development required for formation of the Birchfields seam may have resulted in the development of a mire flora not seen within the short lived mires typical of the Brunner P. The Brunner P Member is relatively thin in the area around Birchfields Opencast. The accommodation of sufficient peat to produce the recorded thickness of coal, may have required space in addition to that provided by basin accommodation. It is possible that peat accumulation formed a raised, rain-fed mire, resulting in accumulation conditions different to that of other Brunner P peat and allowing for the accumulation of a greater peat thickness than would have been otherwise possible.

From drillhole information it can be determined that angiosperm abundance was increasing throughout the lower Paleocene due evolutionary changes that allowed them to compete more effectively against the established gymnosperms. During late Palaeocene thermal maximum (late Brunner P deposition) angiosperms became significantly more abundant than gymnosperms. DH698 data shows a strong correlation between angiosperm abundance and carbon isotope fluctuations associated with climatic warming. This provided convincing evidence that climate as well as evolutionary trends control angiosperm abundance in the Paleocene.

Chapter 5

Summary, discussion and conclusions

5.1 Introduction

The purpose of this thesis has been to determine the reason for the unusual abundance of coal occurrences within the Dunollie Formation in the Southern Rapahoe Sector, and reasons for the high degree of variability in seam characteristics and coal properties. A secondary focus for the thesis has been examination of the relationship between the Dunollie Formation and the overlying Brunner Formation, in order to refine the criteria for a workable boundary.

5.2 Coal Occurrence

5.2.1 Depositional Setting

The conditions leading to deposition of the Dunollie Formation within the Southern Rapahoe Sector were different to those elsewhere in the Paparoa Basin. In the Southern Rapahoe Sector the Dunollie Formation is separated from the massive mudstone deposits of the Goldlight Mudstone Member by the Goldlight Transitional Member. The Goldlight Transitional Member developed due to persistent input of sediment from the northwest into the Goldlight Lake. Deposition occurred as a series of lobate or birdsfoot deltas, where each delta was initially focussed on a point source of sediment entering the basin. Once extended away from the lake margin the deltas lobe thickness and positioning was controlled by a series of localised NNE–SSW faults.

It is proposed that towards the end of Goldlight Transitional Member deposition, the local tectonics changed. Subsidence became focussed north of Rapahoe Township while to the south subsidence slowed allowing for the emergence of the previously sub-aqueous delta plain and the establishment of a floral community. With the development of a flora upon the floodplain, the amount of organic matter deposited increased, allowing for the formation of mires and the deposition of peat. The coals formed from these initial mires mark the stratigraphic boundary between the fluvial coal measures that make up the Dunollie Formation and the sub-aqueous lacustrine deposits of the Goldlight Formation.

Sedimentary analysis of outcrop and drillhole logs shows that two types of fluvial system were responsible for deposition of the Dunollie Formation.

1) Initial deposition occurred as an anastomosing fluvial system, in which overbank deposits are dominant over channel sands.
2) Deposition of the upper Dunollie was by a meandering fluvial system. Sheets of cross-bedded sandstone occur in greater abundance than mudstones and carbonaceous units.

The initial anastomosing fluvial system formed in response to the conditions on the emergent Dunollie floodplain. Channels were relatively confined with vertical accumulation of channel sand dominating over lateral migration by point bars. Overbank deposits of mud and silt combined with organic matter make up the majority of the lower Dunollie. A series of flood ponds, peat bogs and back swamps existed between channels (e.g. Smith & Smith 1980). With the ground surface close to the regional water table and given the proximity of the Goldlight Lake to the southeast, these regions were probably only just emergent.

The transition from an initial anastomosing fluvial system to the meandering fluvial system occurred due to changes in fluvial conditions. As accommodation decreased, deposition of the Dunollie extended further into the basin. The extension of the Dunollie floodplain pushed the Goldlight Lake increasingly to the southeast. This development of the floodplain was accompanied by an overall decrease in gradient. As the angle of the floodplain decreased the ratio of suspended sediment to bed load increased, and the Dunollie fluvial system changed to a meander system.

The meandering fluvial system produced a different style of deposit compared to the anastomosing system. Sheets of fine to medium cross-bedded sandstone dominate the meander deposits. Interbedded with the sandstones are mudstone and carbonaceous beds. Two main factors shaped the mid to upper Dunollie deposits. Firstly the focus of subsidence and the regions main fluvial system remained north of Rapahoe Township, and secondly in the upper Dunollie the meander system became more constrained. Restriction of the fluvial system allowed for the development of persistent widespread mire conditions within the uppermost Dunollie. Constraint of the Dunollie fluvial system may have resulted from the development of erosion resistant plugs made up of fines and organic matter deposited in old meander bends. The continuing development of vegetation on the floodplain will have acted to stabilise levees, adding to the constraint of the fluvial system.

Deposition of the Dunollie was terminated when the northwestern source area experienced a pulse of greater activity. The upswing in activity within the source area resulted in a large volume of coarse sediment being supplied to the basin. The Dunollie mires and fluvial system were overwhelmed by the influx of conglomerate material. This upswing in source area activity was relatively short lived. Reduced sediment supply then allowed for a return to sand dominated fluvial conditions and deposition of the Brunner P. Due to the limited occurrence of Brunner P in outcrop and drillhole, insufficient evidence was available to determine the nature of the fluvial system in which the Brunner P accumulated.

5.2.2 Mire Occurrence

The majority of Dunollie mires were relatively small and short-lived; the exception to this is the New Point Elizabeth mire in the uppermost Dunollie.

In the lower Dunollie Formation mires occurred on the floodplain between the anastomosing channels. Inundation of the mires by flooding was common. These lower Dunollie mires are characterised by very thin (~25-30cm) laterally discontinuous coal bodies. Although inter-bedding with mudstone and siltstone is common, the coals themselves are relatively low in ash. This indicates that during peat accumulation the mire was not subjected to flooding, but when flooding did occur it terminated peat accumulation entirely.

The upper Dunollie contains an unusually thick and persistent coal seam. Containment of the major fluvial system to the north combined with the increasing constraint of the meander system allowed for this development of sustained mire conditions. The thickest peat accumulation in this mire developed in an area north of Seven Mile Creek (figure 5.1). Peat accumulation was terminated by the sediment influx that formed the Brunner Conglomerate Member.

Peat accumulation also occurred within the Brunner P. A thick lens of peat accumulated just south of Trig K No.3 forming Birchfields Seam. Brunner P coal also occurs in the ridge crest west of the New Point Elizabeth Mine. However due to the limited preservation of Brunner P sediments and the disruption to the Brunner P caused by opencast extraction of the Birchfields seam, the fluvial conditions that allowed for mire development remain unknown.

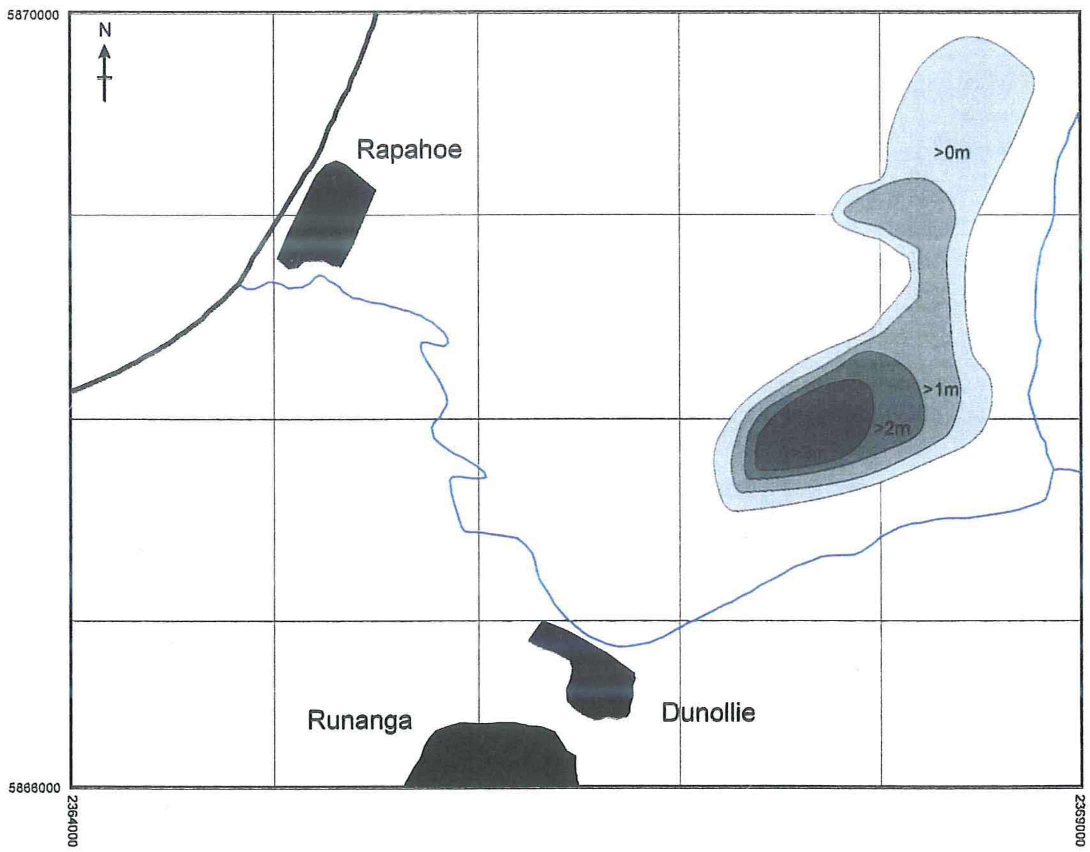


Figure 5.1: Thickness and distribution of the New Point Elizabeth and correlated seams. Thickness and distribution is only approximate due to data limitations. Distribution has also been reduced by erosion, as the seam occurs between 150-200m elevation.

5.2.3 Coal Properties

Coals from the Dunollie and Brunner P have distinctly different coal properties. Sulphur content and volatile matter are generally lower in Dunollie coals, while Brunner P coals have higher tissue preservation index.

Sulphur & Volatile Matter

The absence of a direct correlation between sulphur content and volatile matter in Brunner P coals suggests that sulphur access to the peats occurred a significant time after initial burial. The high volatile matter of Brunner P coals is therefore attributed to the increased abundance of angiosperm material and poorly oxygenated mire conditions.

Tissue Preservation (TPI)

There appears to be no direct correlation between floral type (based on palynology) and TPI in the Dunollie and Brunner P coals. Although angiosperm material is typically more prone to decay then gymnosperm derived material, TPI values are on average highest in the Brunner P coals while angiosperm abundance is also relatively high. Tissue Preservation Index for Dunollie and Brunner P coals is considered to have been controlled by a combination of water level and nutrient supply. High water levels result in a wetter peat, which reduces oxidation and destruction of tissue structures. Abundant nutrient supply results in stronger more robust plant growth. The supply of robust plant material to the mire results in a peat with tissue structure less prone to decay and degradation.

5.2.4. Floral Change

Angiosperms seem to have mainly occupied floodplains and mire margins in the late Cretaceous, and were still not dominant under true mire conditions in the Paleocene. Hence, in thicker seams angiosperms are abundant near the seam floor, and decline as the mire became more established and conditions within the mire became harsher. Similarly, thin seams where mire conditions only just became established often contain abundant angiosperm material.

Angiosperm abundance does show a trend of increasing through the Dunollie and into the Brunner P. There appear to be two factors contributing to this increase. Evolution during the early Paleocene allowed angiosperms to compete more effectively with gymnosperms. Secondly the Paleocene represents a relatively warm climatic period, with average temperatures peaking during the late Paleocene, and angiosperms appear to compete more successfully with gymnosperms under warm conditions.

A marker associated with the late Paleocene thermal maximum is an anomaly in the occurrence of $\delta^{13}C$. Angiosperm abundance within the Dunollie and Brunner P shows a strong correlation with the $\delta^{13}C$ anomaly, indicating that this period of warmth allowed angiosperms to become more abundant than gymnosperms.

5.3 Dunollie – Brunner Boundary

It is proposed that the revised stratigraphic system of Ward (1997), which elevated the Jay, Ford, Rewanui, Goldlight and Dunollie members to formation status and the Paparoa Formation to a Group, be accepted and extended to include the material classified as Brunner within the Greymouth Coalfield. The stratigraphy of the Dunollie and Brunner material at Greymouth requires revision to make this possible.

It is proposed that the Brunner be divided into two separate formations, the Brunner Formation and the Paleocene Brunner Formation. The Brunner Formation is made up of all of the Eocene Brunner material identified by Gage (1952) and Nathan (1978), while the Paleocene Brunner Formation is made up of two members, the Brunner P and the Brunner Conglomerate Member. The Brunner P includes all of the Paleocene Brunner coal measures while the Brunner Conglomerate Member contains all of the conglomerates previously assigned to both the Brunner and Dunollie (Gage 1952, Nathan 1978). The new Brunner Formation should then be included into the Rapahoe Group as it represents the first deposit of the regional marine transgression, while the Paleocene Brunner Formation forms the uppermost formation in the Paparoa Group.

The separation of the conglomerates from the Dunollie allows the upper boundary of the Dunollie Formation to be defined by a similar method to that applied by Ward (1997) to the remainder of the Paparoa Group. The Dunollie Formation as a coal bearing division of the Paparoa Group is defined as the sediments occurring between the first sustained carbonaceous occurrence above transitional lithosomes till the last carbonaceous occurrence below conglomerates.

These proposals resolve several difficulties with the current stratigraphic system.

- The conglomerates in the central portions of the basin no longer require division into Dunollie and Brunner components based on the relatively subjective criteria of whether quartz or lithic clasts are more abundant.
- The regionally extensive Eocene Brunner material is distinguished from the Paleocene Brunner, which is limited in occurrence to the Greymouth Coalfield.
- All of the Brunner material can now be assigned to coherent Groups.
- The boundary definitions for the Dunollie Formation and Paleocene Brunner Formation are in line with those proposed for the remainder of the Paparoa Group.

5.4 Suggestions for Future Work

The Dunollie Formation within the study area of this thesis, i.e. the Southern Rapahoe Sector, does not warrant further investigations in isolation. However, information from within the Dunollie and bounding Formations on a basin-wide scale would be valuable, as follows.

- Improvement of the resolution of the PM3 palynological zonation and potential subdivision of the PM3 zone. The current PM3 zone encompasses all of the Dunollie and Paleocene Brunner Formations making formation assignment difficult for sediments without a stratigraphic context. A subdivided PM3 zone could provide a useful stratigraphic tool; e.g. allowing isolated outcrops to be assigned to specific formations when the stratigraphic position is unclear and sedimentary character is not diagnostic.

- Detailed examination of the relationship between δ^{13}Carbon-isotope and angiosperm abundance because the Brunner P provides an opportunity to examine climatic change during the Paleocene from a terrestrial setting.

- Initial palynological investigations indicate that the Paleocene Brunner Formation is separated from the Brunner Formation by an unconformity of ~10my. Work is needed to locate and map this unconformity within the Greymouth Coalfield. Such an investigation should also include detailed refinement of the palynological criteria for distinguishing the boundary.

- Examination of the proposed Paleocene Brunner Formation. It is suggested that a future investigation map the extent of both Brunner P and Brunner Conglomerate Members.

- Renaming of the Paleocene Brunner Formation, in order to distinguish it from the regional Brunner Formation.

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cornflakes

Appendix 1

Sampling locations

The following section provides a location and sampling descriptions for the material recovered during the fieldwork. Figure A1.1 shows the relative sample locations on an idealised stratigraphic column.

Sample CN1: Sampled from beside DH 791, CN1 represents the thickest seam identified from the Dunollie Formation. The 3.3m thick seam was channel sampled for chemical analysis and multiple block samples were taken for petrographic work. The petrographic samples taken are the CN1 suite from 0.9 to 3.1, where the number represents the sample location within the seam measured from the roof in meters. The seam sampled is thought to be the equivalent to the seam worked by the New Point Elizabeth mine.

Sample CN6: The three seams seen in figure 3.4 were sampled, resulting samples CN6 S1, S2, and S3 U/L with S1 being the highest seam and S3 the lowest. The three seams are 30cm, 25cm and 45cm thick respectively. Petrographic blocks and chemical samples were taken.

Sample CN7: Located on the road north of Trig K, this sample was taken from a series of thin highly deformed seams interbedded with clastic sediments. A block sample was taken.

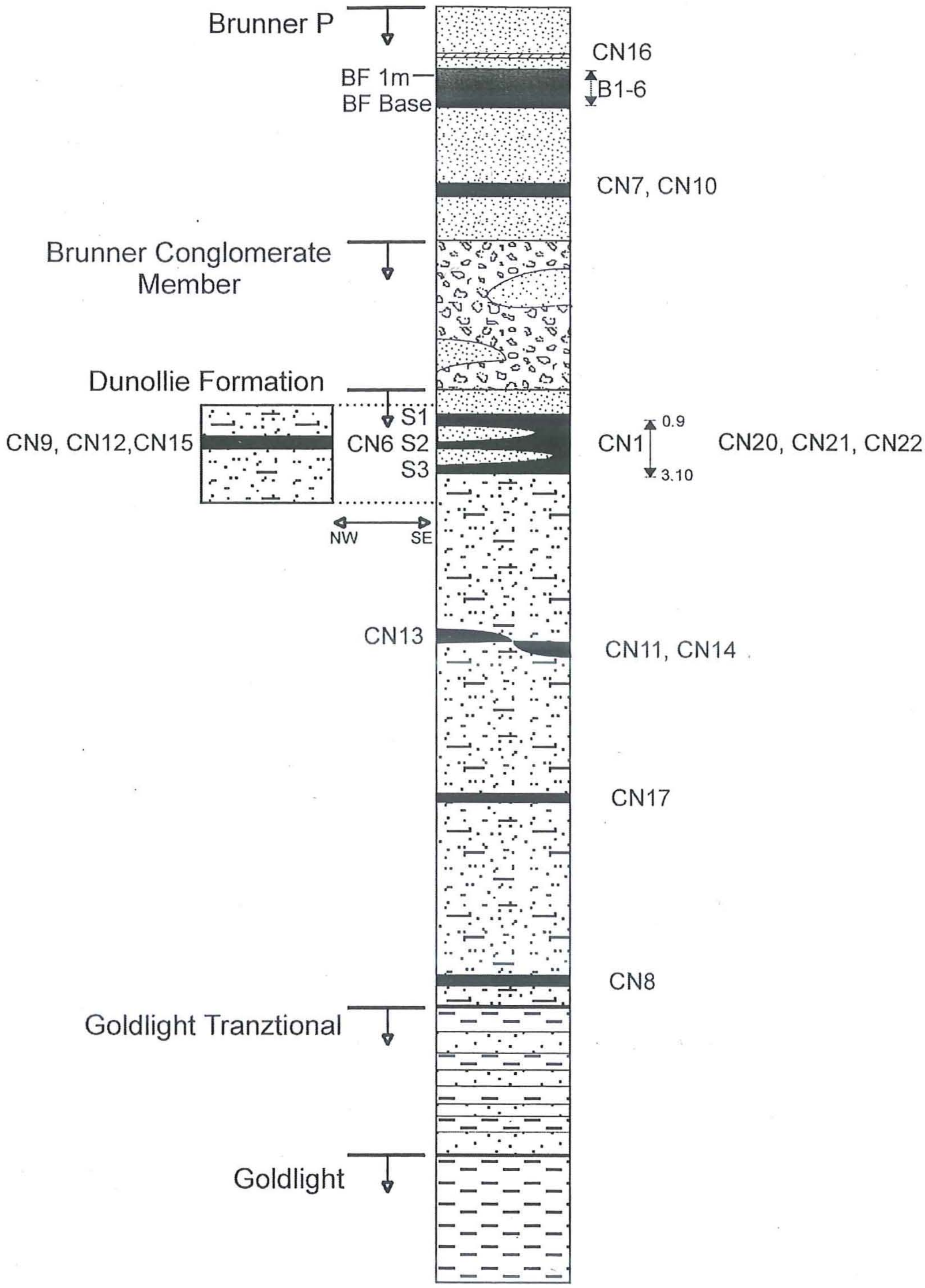

Figure A1.1 Relative sample locations

Stratigraphic column is theoretical and not meant to represent an actual outcrop.

Sample CN8: This sample comes from the lowest seam exposure found. Found in the stream below sample location CN6, CN8 consists of a series of thin seams (<20cm thick) that lens in and out of Dunollie sediments, a block sample was taken from the thickest seam.

Sample CN9: Taken from the continuation of CN6 north along the cliff face (left side if figure 3.3). The seams sample at CN6 have thinned to <10cm. Seam lens in and out with two seams present over most of the exposure. Block sample collected.

Sample CN10: ~100m West of CN1 a 35-40cm thick, seam of Brunner coal is exposed in a road cutting. Coarse quartz rich grit and coarse sand bound the seam. Block sample collected.

Sample CN11: Sampled from thin (<10cm) lenses of coal located on the eastern side of the main ridge ~20m below the Dunollie – Brunner contact.

Sample CN12: 15cm thick seam just below the Dunollie – Brunner contact, comparable to CN6 except only one seam is present.

Sample CN13: Found 20m below CN6. Up to 35cm thick the seam has limited exposure, with minimal out crop indicating that the seam continues to the north. Potentially related to CN11.

Sample CN14: Found on the eastern side of the main ridge at the base of a small waterfall, CN14 is of uncertain stratigraphic position, the sample face appeared to be

Dunollie material however, floating blocks of Brunner material were common on the surrounding slope.

Sample CN15; Very thin Dunollie seam located just below the Brunner on the ridge crest half way between Trig K and DH791.

Sample CN16: Located in the upper Brunner P east of DH 791, CN16 is unusual as it comprises of ~1cm rounded quartz pebbles in a matrix of carbonaceous material, microscopic examination revealed the matrix to be a mixture of clay and vitrinite fragments.

Sample CN17: 80cm of dirty coal and muddy interbeds located halfway between CN8 and CN13

Samples CN18 and CN19: Located south and east of CN6 these two samples are taken from the continuation of the seams exposed in CN6, the exposed material ranged from 25-40cm in thickness.

Samples CN20, CN21: Taken from the southern portal openings of the New Point Elizabeth mine. Seam sampled was only ~30cm thick at the mine entrance but thickened into the mine, exact measurement s were not taken due to the unstable nature of the location.

Sample CN22: A thick seam of highly weathered coal exposed to the north east of the New Point Elizabeth mine entrances. Seam is approximately 1.6m thick with a dip parallel to the ground surface. The same or an equivalent seam to those sampled in CN1, C20 and CN21.

Samples B 1-6: R Boyd sampled these blocks from a Brunner P seam located to the west of New Point Elisabeth Mine. The blocks were taken in a continuous sequence from B1 at the seam roof to B6 at the floor.

Samples BF1 and BF base were taken from Birchfields Opencast during operation in the 1980's. BF1 was sampled from approximately 1m below the seam roof, while BF Base was sampled from the seam floor.

Appendix 2

Preparation of polished block mounts for petrography.

The nature of the Dunollie coals presented several problems with respect to the collection and preparation of samples for petrographic analysis. Coal blocks proved highly friable and especially subject to breakage during the polishing process. Consequently standard mounting and polishing techniques required alteration to produce high quality orientated, polished block mounts.

Block samples were manually extracted from Dunollie coal seams after some work was undertaken at each locality to freshen the outcrop. This consisted of breaking away the outer weathered layers of material. Blocks ranging in area from 3 – 10 cm^2 were extracted, and then wrapped in aluminum foil to provide structural support. Each sample was then labeled to identify location within the seam and a younging direction within the block. Sample locality and the seam position information were also recorded. Samples were then sealed in waterproof bags for transportation out of the field. As an additional measure to preserve the blocks intact, sample bags were carefully wrapped in newsprint prior to transportation back to Christchurch.

Due to the weathered and highly friable nature of the Dunollie coals, standard mounting procedure, which consists of cutting the block to be mounted and polished directly from the field sample, failed. The final method required the entire field sample still in its foil wrapper, to be boxed and then fully immersed in a bulk epoxy resin. The sample is then vacuum impregnated with the epoxy resin and allowed to harden overnight at 40°C. The dry impregnated samples were cut using a diamond saw into 4cm by 3cm blocks, with the face to be polished orientated at right angles to the bedding of the seam.

The blocks were then mounted in standard mounts using Gougeon – West Systems – Slow Epoxy. Once again the samples were vacuum impregnated and allowed to set overnight at 40°C.

Polishing was preformed using standard wet polishing techniques and a Leco Vari/Pol 150 auto-polishing unit. 180, 400 and 600 grade polishing papers were used for the initial exposure of the coal surface. Polishing with a PanW paper and 1μm diamond suspension solution followed. The final polishing phase consisted 45 seconds with a sevit cloth and silica suspension solution in order to accentuate the surface relief.

Problems associated with the polishing process

The weathered nature of the samples combined with the low rank and high levels of clay minerals resulted in polishing blocks that were subject to pitting and scouring of the block surface during the final polishing process. A method was devised to repair samples that were scratched by material lifting off the surface of the block during the last two stages of polishing.

Affected blocks were replaced in their mounting molds polished face up. The face of the block was cleaned with ethanol to remove any optical oil or other grease from handling of the block, and then dried thoroughly. A very small amount of mounting resin was applied to the polished surface, just enough to form a thin layer covering the entire face of the block. The block was then placed in a vacuum flask for 60 – 120 seconds in order to draw the resin down into the face of the block. The treated block was then dried overnight at 40°C.

The repaired and sealed block was then re-polished starting with the PanW paper and 1μm diamond solution. Provided care was taken in the re-polishing process and treatment with the silica solution was kept to a minimum, this method produced blocks suitable for point counting and photography.

A problem was experienced in the maceral analysis of some blocks when discoloration of the block surface occurred due to the apparent seepage of natural oils from within the coal blocks. This oil filming resulted in blurring and discoloration of the macerals making distinction of exact maceral type extremely difficult. An example of this problem is illustrated in figure A2.1. The polishing process appeared to aggravated the problem in the blocks subject to this occurrence, as the polishing mount compressed the coal forcing more oil out of the fractures at the same time the polishing medium spreads a thin film of the oil across the coal surrounding the fracture. This effect then develops further over the days following polishing until margins of 1-2 mm extended around the fractures. Samples where this proved a major problem were re-polished and maceral counts performed immediately.

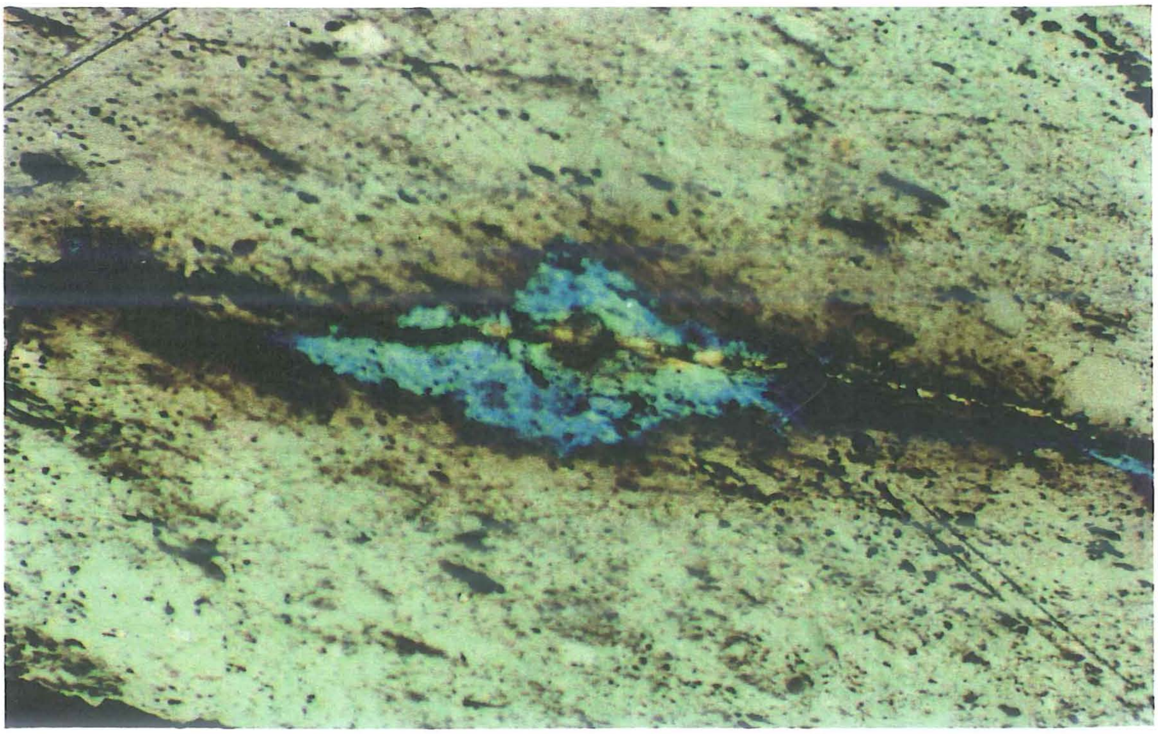

Figure A2.1: Oil contamination of polished block

Appendix 3

Adjusted Drillhole Data

	Thickness Recorded		
		Goldlight Member	
DH number	Dunollie	Transitional	Mudstone
433	82	?	ND
623	0	0	ND
624	0?	ND	ND
626	96	59.5	18
628	51	6	74.4
631	45	18.2	ND
633	62	49.7	41
636	71.5	11	109.8
637	196	0	0
638	91	33	112
640	102	0	ND
642	84	44.1	91.4
643	180-	18	72.2
644	91	23.8	86.6
645	250	27.7	90
646	105	13.8	83.2
647	187	34.7	0
648	66	?	67.7
649	96	34	58+
650	72	13	79.5
653	75	32.8	48.7
695	94	22.1	?
696	67	27	108
697	80	11.2	89.4
698	50	21.2	98
699	174	32	58.3
700	0?	45	62.4
701	67	15.7	94.9
702	77	66.1	0
703	82	35.7	67
704	103.5	47	76
705	97	16.7	ND
706	98	45.6	66
711	103	6.5	ND
712	87	26	96
713	43	39	105.5
714	93	34.1	72.9
715	90	42.6	ND
716	96	44.1	63.8
725	98	15	89
726	120-	27	ND
765	68	16	84.5
766	84	ND	99

	Thickness Recorde		
		Goldlight Member	
DH number	Dunollie	Transitional	Mudsto
767	82	20	ND
769	ND	ND	101
771	ND	0	102
773	ND	ND	111
775	ND	ND	58.17
776	ND	ND	73.04
777	34+	ND	54.42
780	ND	ND	108
792	ND	ND	119
794	ND	ND	115
797	ND	0?	114
798	ND	0?	121
799	83	12	ND
811	105	14	ND
815	62	14	ND
818	102	20	ND
819	74	14.5	114
822	ND	ND	116
833	77	16	125
834	70	19	134
835	ND	ND	118
836	103	ND	ND
837	ND	ND	112
838	ND	ND	138
850	72	45?	ND
851	98	32	ND

ND = No Data for this portion of the Drillhole

+/- Thickness is a maximum or minimum

? Thickness uncertain, poor quality information

Appendix 3: Adjusted Drillhole Data

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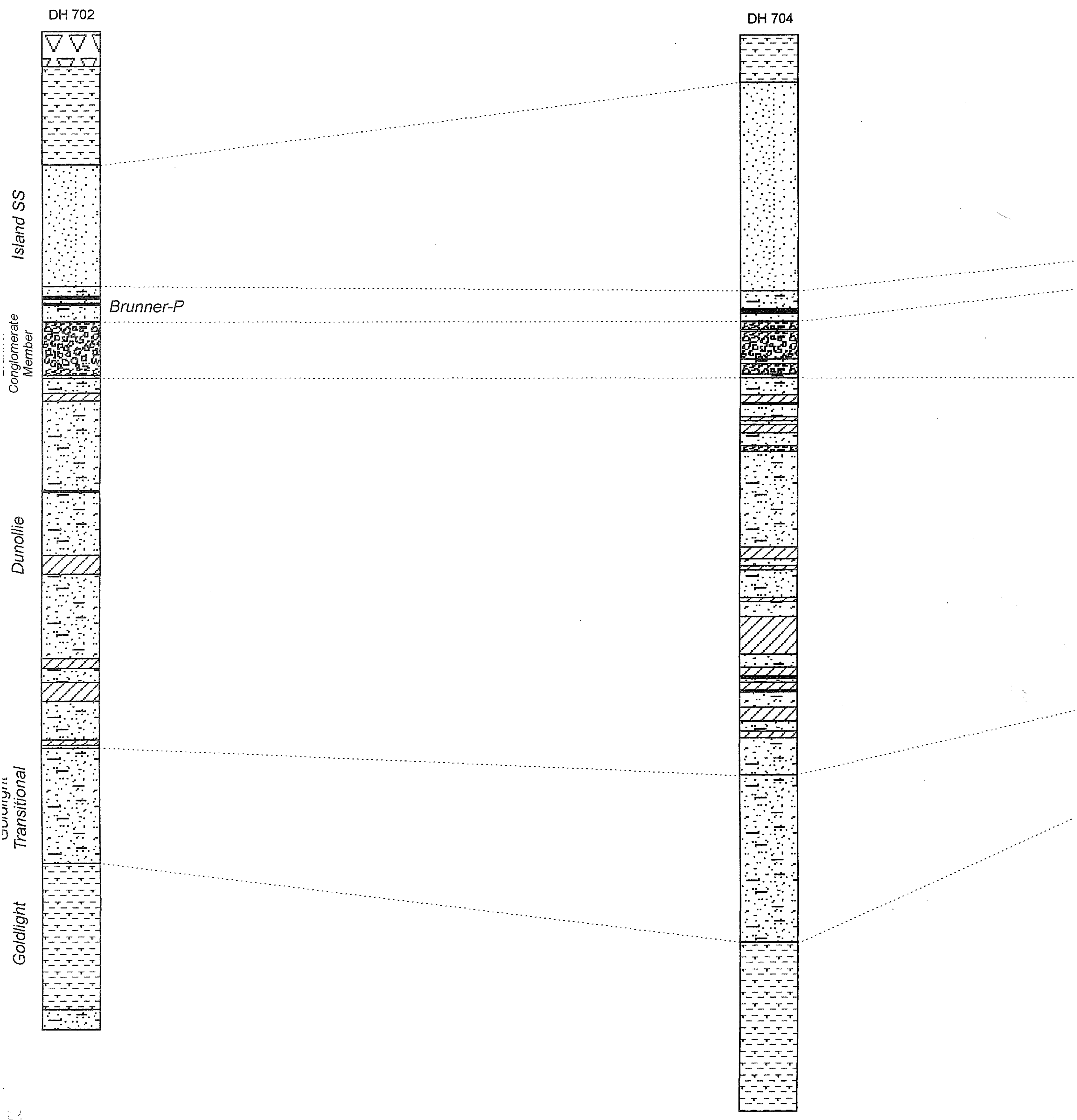
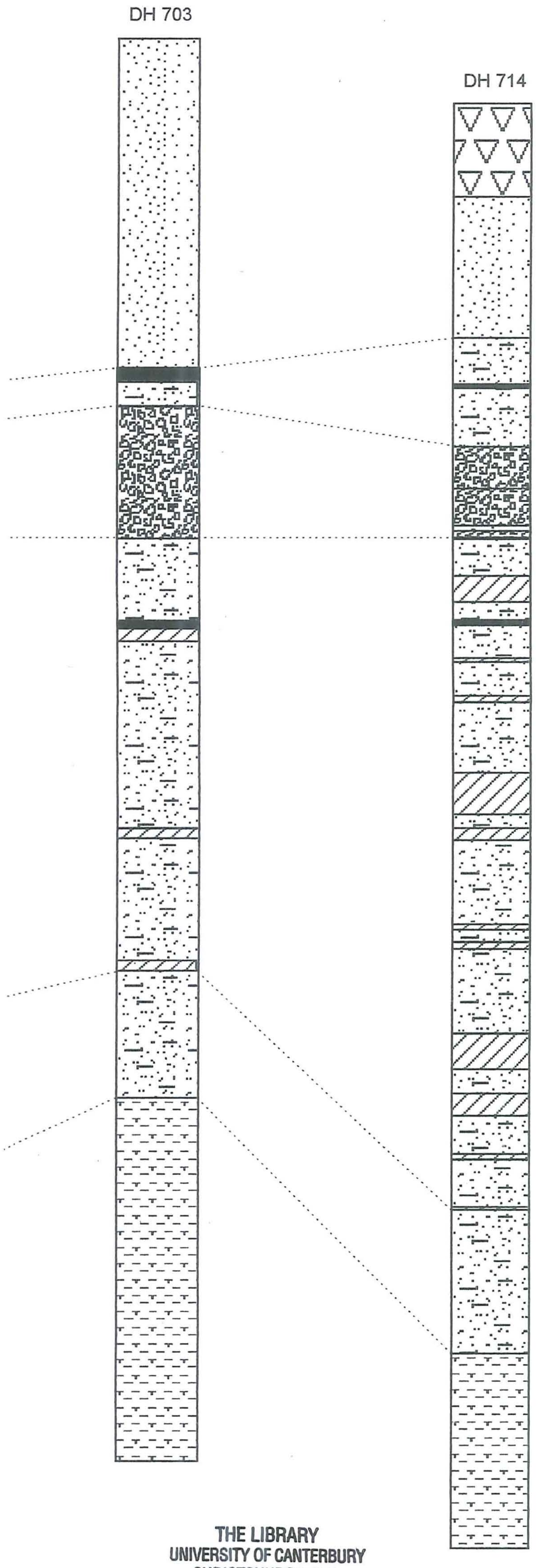


DH 702
DH 704
Island SS
Brunner-P
Conglomerate Member
Dunollie
Transitional
Goldlight



Legend to Accompany Cross Sections 1-4

Sandstone: Medium to fine grained sand, often bioturbated, commonly with associated glauconite. Within the Island SS calcareous cementation common.

Interbedded Sandstone and Mudstone: Typical Brunner and Dunollie sediments. Medium to very fine quartz sands interbedded with grey to black mudstones. Mudstones often highly carbonaceous to coaly in nature.

Conglomerate: Brownish white to grey white, grades from fine pebbly to coarse. Quartzose with minor Greywacke lithics, lithic component increases downwards, until the lithics dominate over a minor quartz component.

Carbonaceous rich zones: Generally mudstones with a high proportion of carbonaceous material, some small coal lens and thin seams. Limited sandstone material, generally very fine grained to muddy, moderately bioturbated.

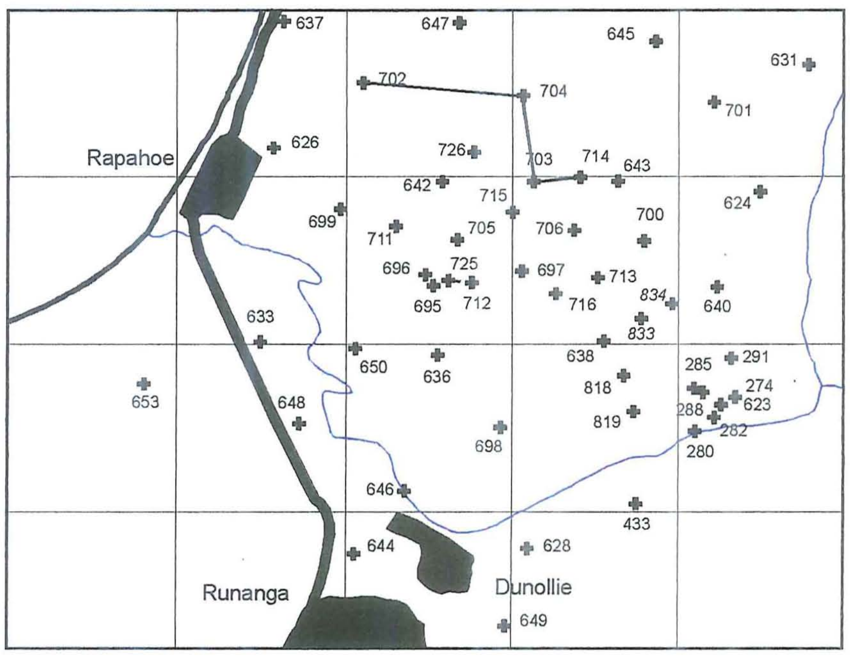
Mudstone: Light to dark grey lacustrine mudstone, massive, often with well preserved leaf / plant material. Limited fine sand restricted to thin discontinuous horizons.

Coal: Brownish-black to black often muddy. Common resin grains and / or pyrite. Pyrite increases towards the roof of seams and up sequence. Seam thickness may be overstated due to interpretation constraints from geophysical logs and common caving, crush zones and fault repetition.

Recent / Disturbed Material: Zones of disrupted material related to recent land slips or mining activities. A crushed mix of units nearby and up slope.

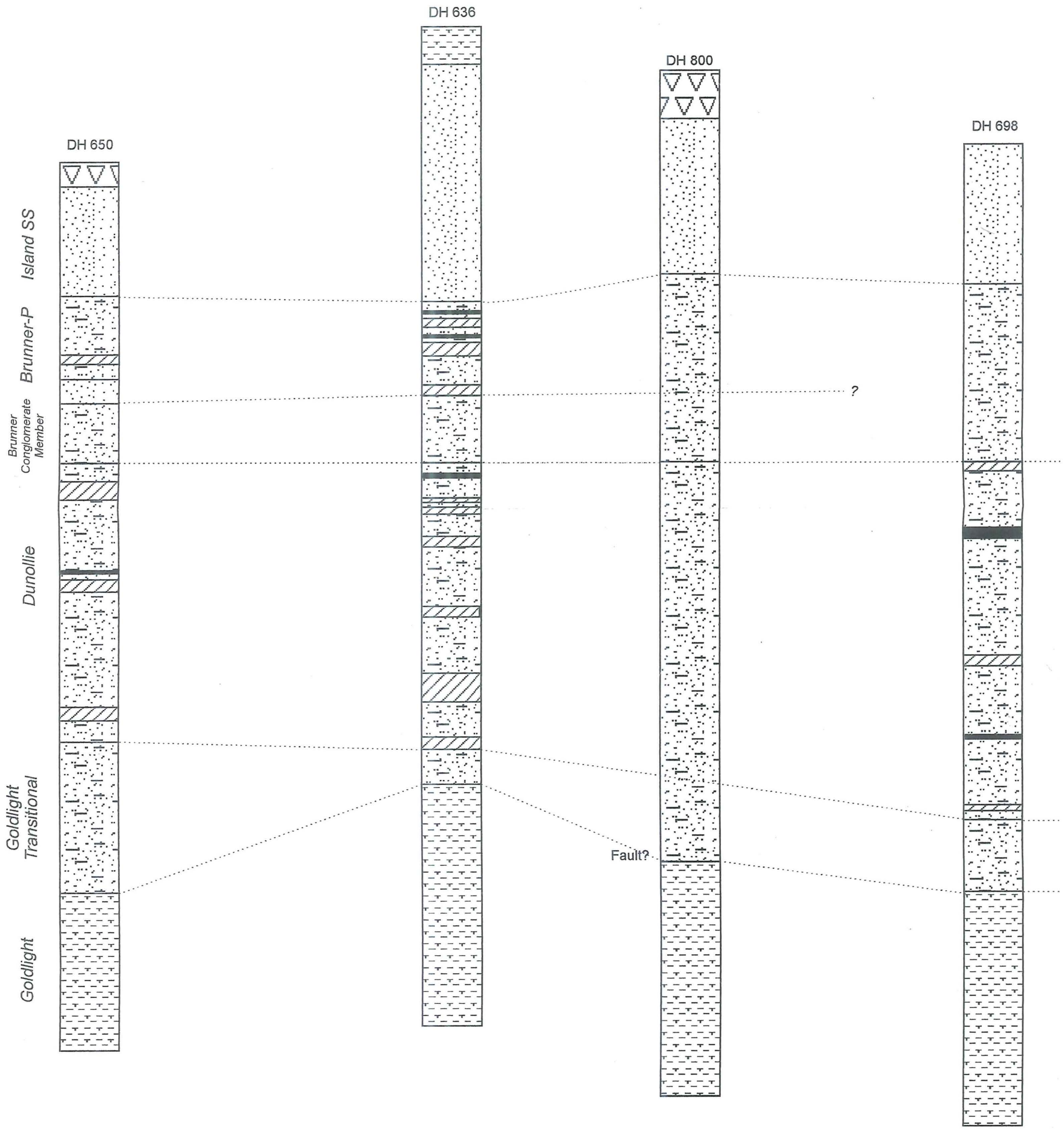
Vertical Scale 1 : 1000   Horizontal Scale 1 : 5000

Location Map



Sheet 2

Note: See Sheet 1 for legend in



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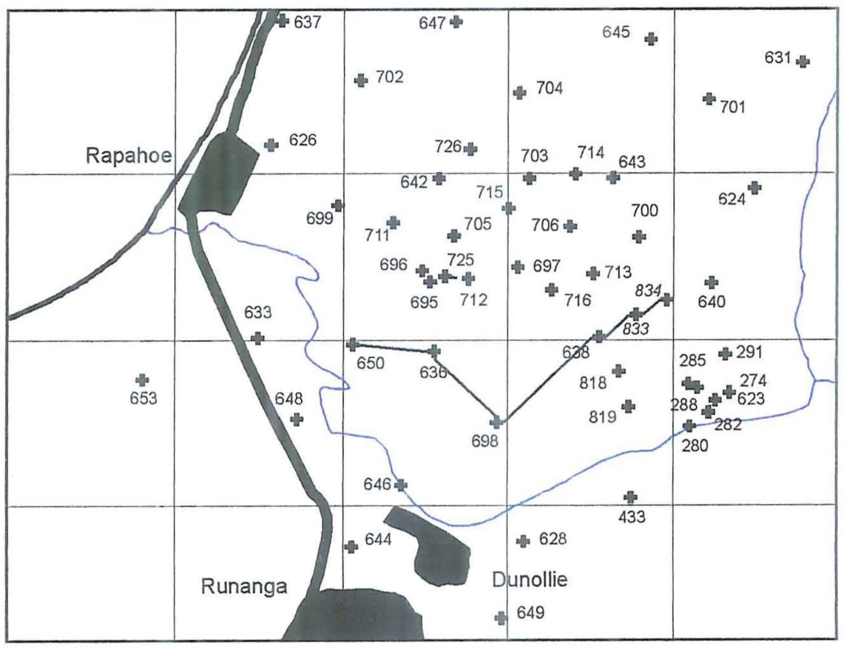

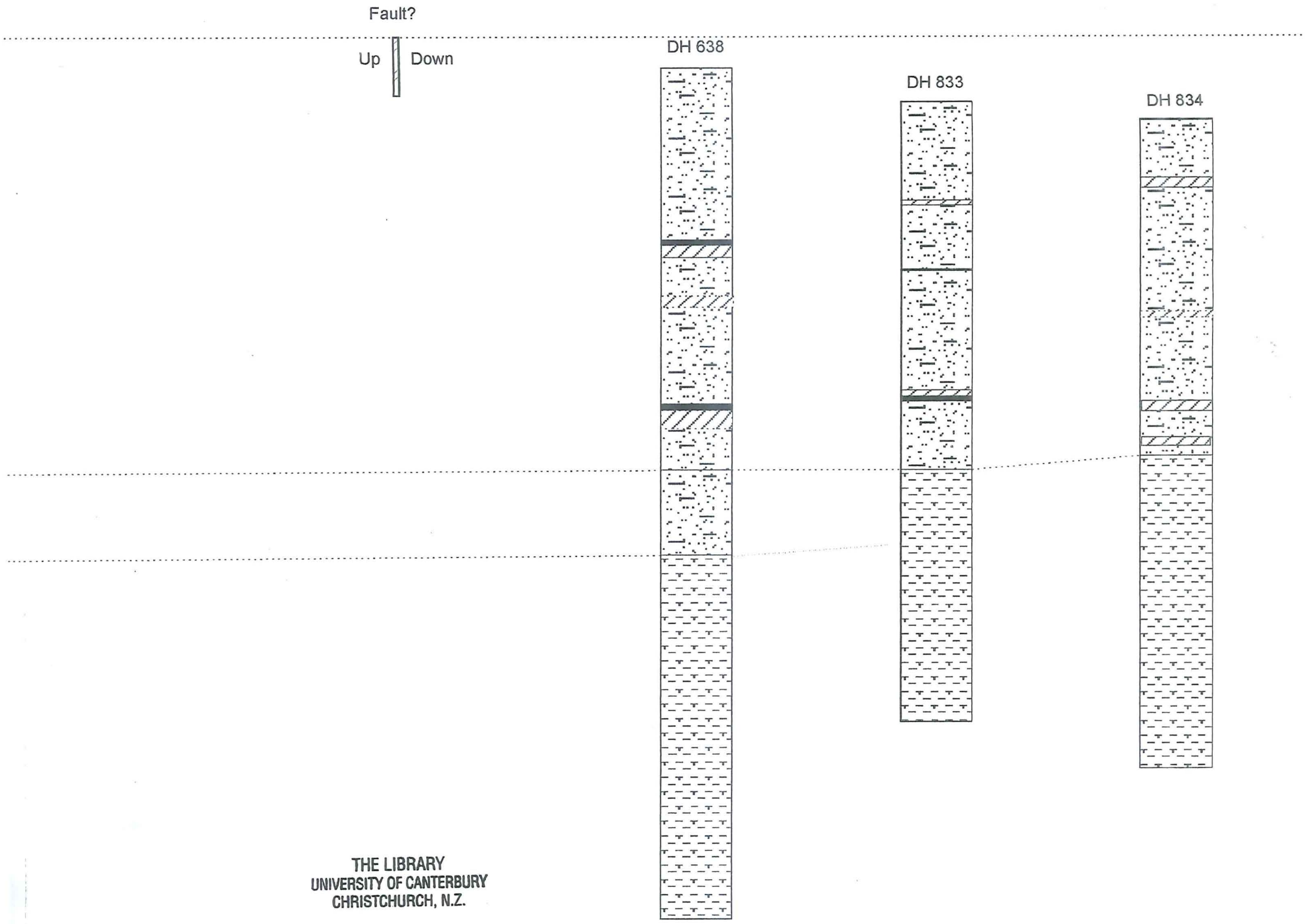

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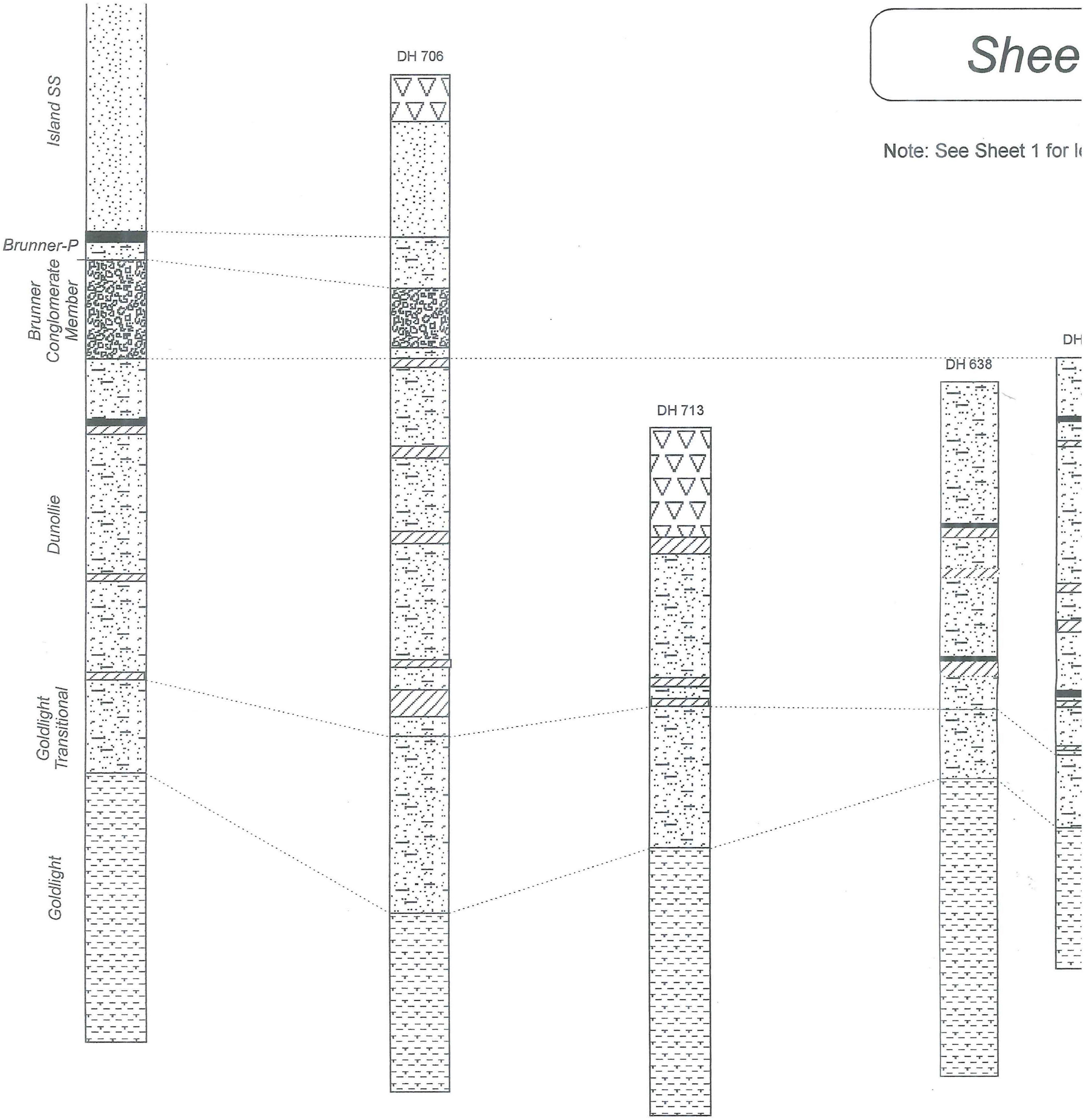

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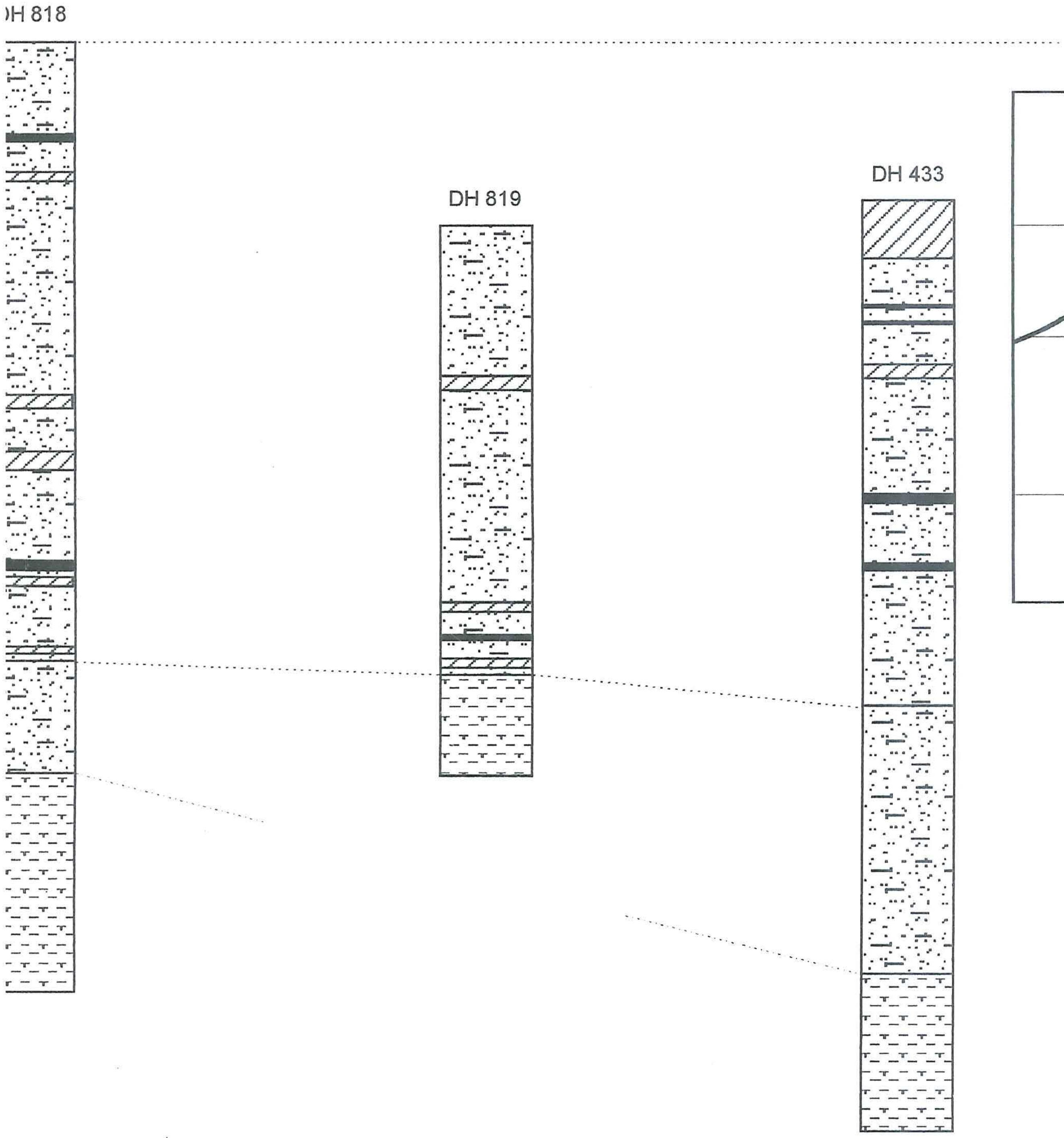

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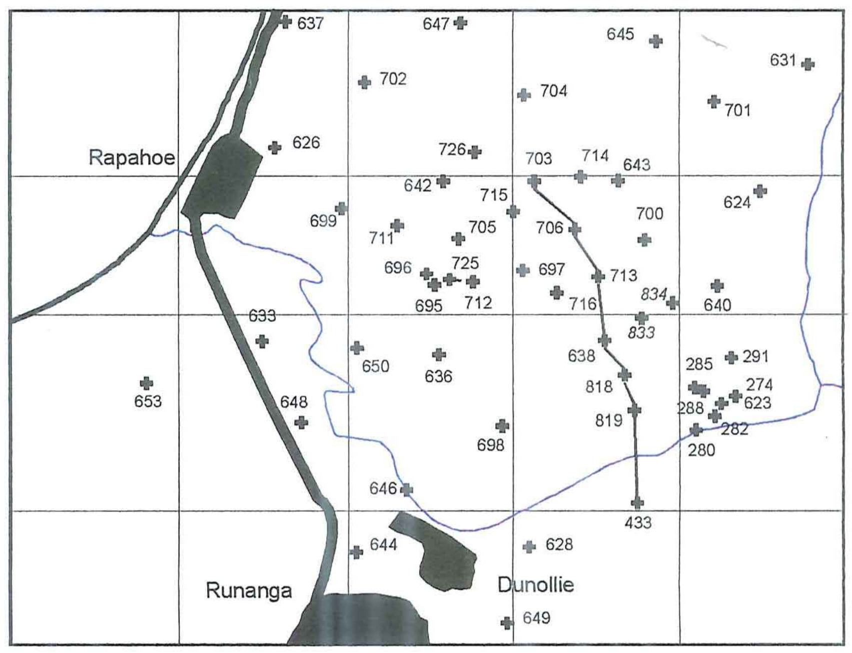

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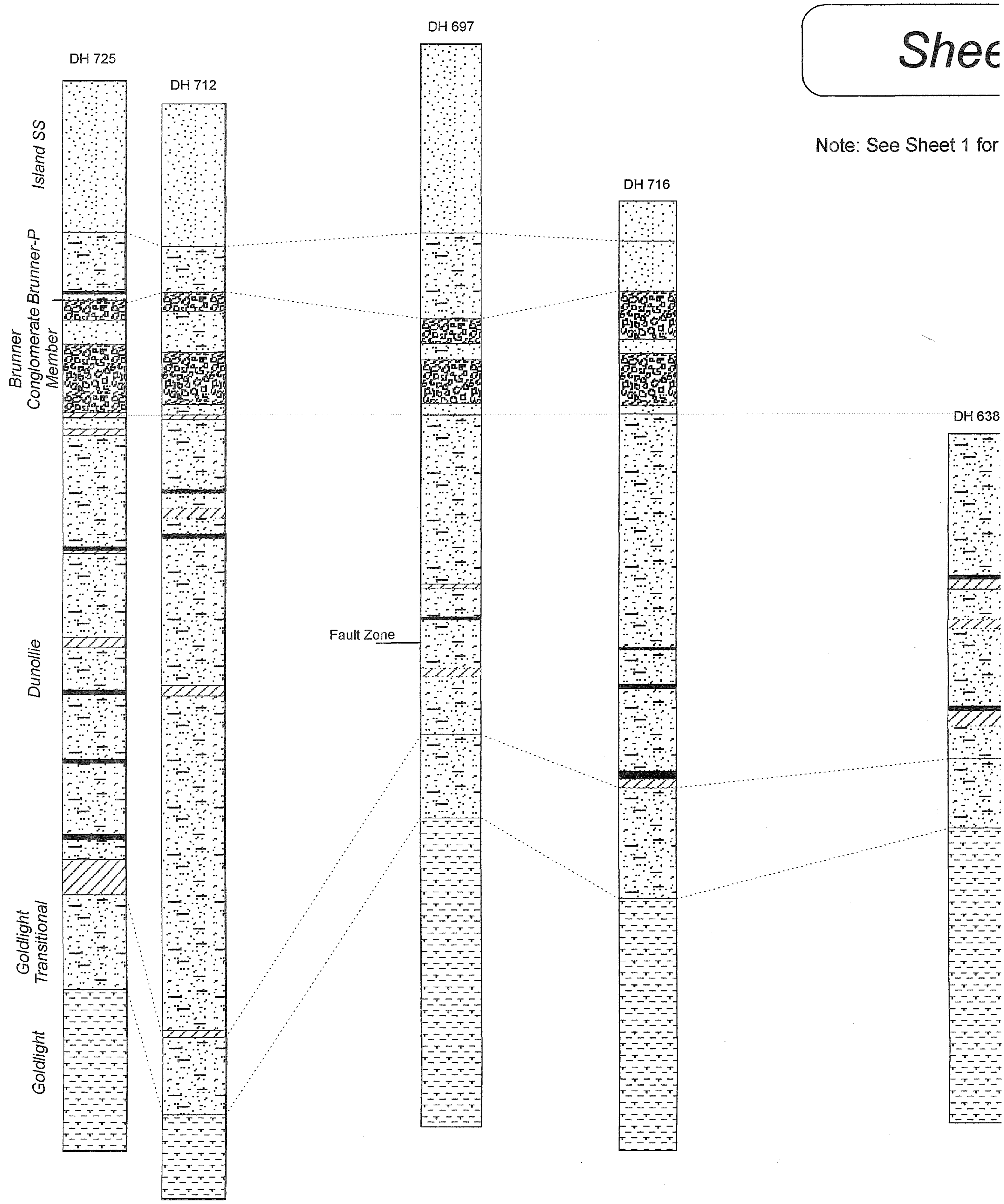

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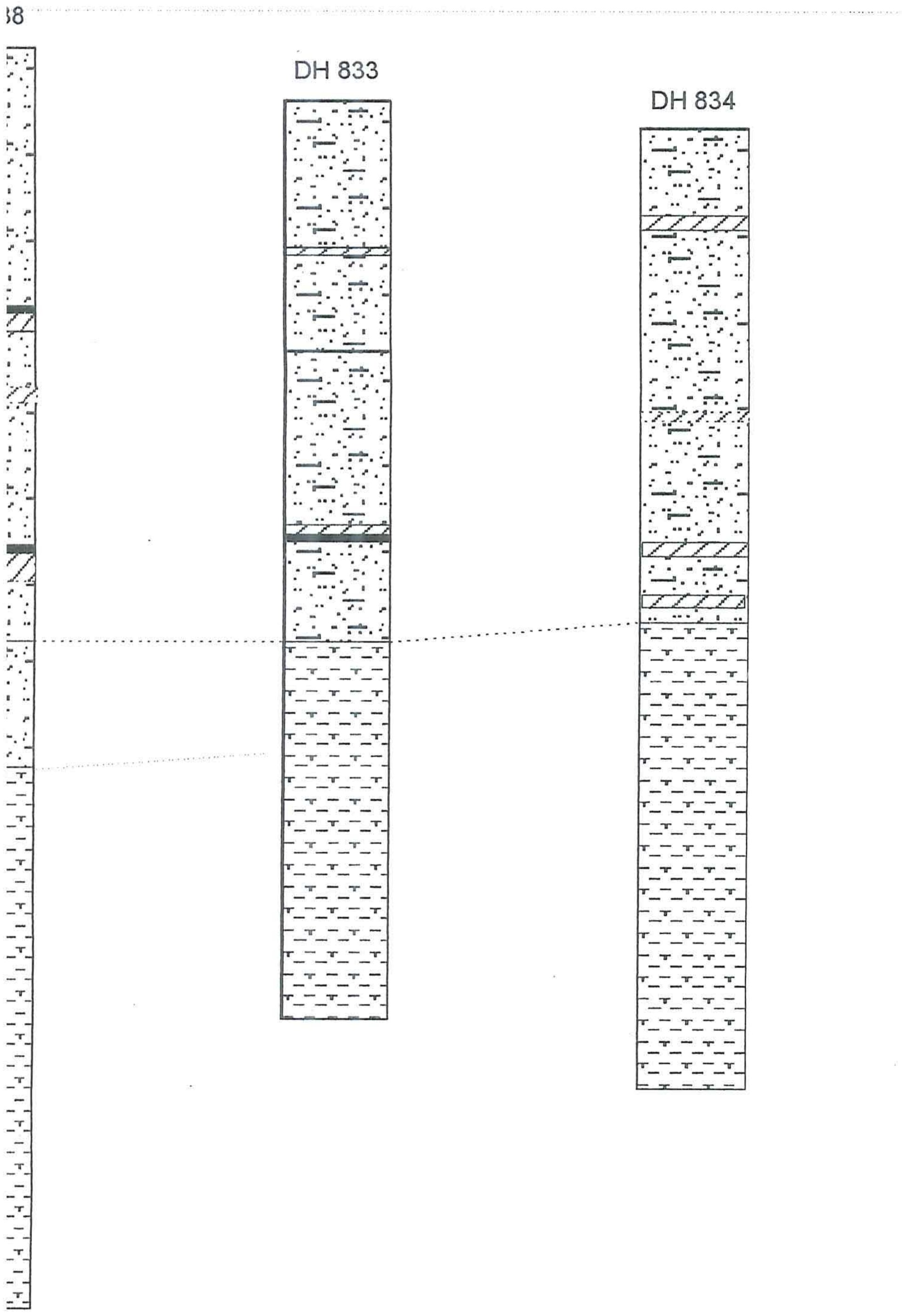

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